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Results of Swine Breeding Research

At the Regional Swine Breeding Research Laboratory and the cooperating State Experiment Stations of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, and Wisconsin.

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CONTENTS

SUMMARY

The background of breeding methods, some of the early experiments in inbreeding small animals, and early experiments in swine breeding are discussed briefly. Developing means of improving the established

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pure breeds, forming new breeds with new combinations of characters superior to the old breeds, and finding means of using breeds so that further increases in performance can be obtained through crossing are the experimental problems recognized. The research relates mainly to the consequences and use of inbreeding, the crossing of inbred lines, selection for improvement of performance characters, including desirability of carcasses, and physiologic problems in breeding performance. Selections have been based on productiveness of sows, growth rate of pigs, economy of gains, and desirability of carcasses.

Approximately 100 inbred lines within 7 breeds have been started. About half of them have been dropped because of poor performance. Two new breeds have been formed from crossbred foundations. Five other crossbred foundations are on trial. Lines have generally become differentiated genetically in respect to performance characters when inbred 25 to 35 percent. Litter size has usually shown some decline by the time inbreeding reached 25 to 35 percent. Growth rate has declined in most of the lines as inbreeding increased. Economy of gain seemingly has improved in some lines. Apparently economy of gain is affected less by inbreeding than are litter size and growth rate.

In the combined data of 6 projects, the selection averaged approximately one-third pig more per litter for number farrowed, two-thirds pig more per litter for number weaned, 22 pounds more for weight per litter weaned, and 15 pounds more per pig for 154-day weight. Selection in some of the best performing lines which are now on hand has been considerably more effective than the average, particularly for numbers farrowed and weaned. Response to selection in some cases has been reasonably close to expectation, but generally selection for performance characters has been less effective than expected in view of the heritability of the characters.

Estimates of heritability—the extent to which a character is controlled by inheritance—for some of the performance characters were calculated. For number of pigs farrowed per litter these range from 10 to 44 percent; about 15 to 17 percent is suggested as a reasonable estimate. Heritability of number weaned ranged from 15 to 32 percent, and for litter weight 7 to 16 percent. Performance of individual sows within the same group appears to be repeatable from one litter to another to the extent of about 16 percent. Two estimates for heritability of economy of gain were obtained, one was 25 and the other 57 percent. Estimates for heritability of growth rate based on weight at 154 days of age ranged from 17 to 40 percent. Heritability of rate of gain from weaning to 200 pounds appears to be higher than for weight at 154 days. Scores for conformation gave an estimate of 20 percent for heritability. An estimate of 15 percent was obtained for heritability of hernia; in addition the sow seems to have a definite maternal environmental influence on the occurrence of hernia in the litter, which is not understood.

Crosses of inbred lines of the same breed usually have shown advantages in growth rate in comparison with noninbred stock of the same breed. When three or more lines were represented in the crosses, the number of pigs raised per litter usually exceeded the number raised in litters from noninbreds. Crosses of lines of different breeds have generally shown higher levels of performance than crosses of lines belonging to the same breed. Results indicate that lines

should be selected for "nicking," or combining ability, to get the most from line crossing, within a breed and between breeds.

Structural and physiologic abnormalities in the reproductive tract were found to be responsible for some of the irregular breeding, low fertility, or complete sterility which occurs in both inbred and non-inbred sows. Age of gilts at time of breeding showed important effects on the number of eggs shed and the number of pigs farrowed per litter.

Records on carcasses of the various inbred lines and line crosses have shown definite differences between lines in carcass characteristics. Hogs of some of the inbred lines consistently yield excellent carcasses, while some lines yield excessively fat carcasses. Carcasses from line crosses out of lines which differed definitely in carcass characteristics generally were intermediate between the parent lines with regard to individual items. Usually the combination of characters expressed in crosses produced carcasses which were superior in desirability to either of the parent lines. Yield of the five primal cuts appears to be the most satisfactory single measure of carcass desirability which has been used but it does not evaluate quality of cuts. Composition of carcasses was altered by subjecting hogs of similar breeding to different levels of feeding.

INTRODUCTION

Improvement of hogs through breeding has been achieved largely through developing and maintaining many herds of purebred swine. These herds have provided a source of purebred boars for use by farmers in producing market hogs. The various breeds are used in purebreeding, grading-up toward a breed, and crossing to produce market hogs. Breeds are the result of both independent and cooperative effort of private breeders, with the exception of some new breeds which have been added recently by experiment stations.

Methods employed in forming and improving breeds included crossing of selected stocks, inbreeding crosses among themselves, line breeding usually to a choice sire, and selecting for type and performance. Some breeders have been much more successful than others. How much of this was due to their genuinely superior skill and how much to natural variation in the results of trial-and-error methods is not known. Soon after the new breeds were recognized as such, breed associations were organized to maintain pedigree registration and to promote the sale and use of pedigree stock. When registry associations were organized, registration of animals crossed outside the breed was denied. Inbreeding had always been in general disfavor, but many had practiced it when a breed was very small, rather than introduce outside blood. Line breeding was practiced irregularly. But breeders have continued to employ selection in striving to improve their favorite breed in type and performance. In recent years, evidence of improvement within the various breeds for some important performance characters such as number and vigor of pigs is not so clear as in respect to type and conformation.

Increased emphasis is now being placed on production characters in swine, in the hope of getting more response to selection than seemingly has been the case in recent years. Since their beginning, swine record

associations have requested that a breeder include in his application for registry of individual animals the number of pigs born and raised in a litter. Litter testing, in which Denmark has led, is an attempt to improve selection practices largely by progeny test and sib test and with respect to carcass qualities which can be measured only after slaughter. Swine record associations in the United States have initiated "registry of merit" or "production registry" during the last 20 years, an action which reflects their desire to improve the effectiveness of selection for performance.

The basic laws of heredity were discovered by Mendel nearly a century ago and were brought to general attention in 1900. Darwin had pointed out in 1859 that the laws governing inheritance were for the most part unknown and that no one could explain why the same character in different individuals of the same species or in different species is sometimes transmitted and sometimes not.

In substance, Mendel discovered that inheritance is determined by paired elements in the germ cells. These paired elements, now called genes, separate when reproductive cells are formed, so that an individual transmits to each offspring one or the other but not both of the genes in each pair it possesses. Accordingly each parent transmits to each offspring a sample half of its own inheritance. Operation of this sampling process is governed by chance, except that each sample must contain only one gene of each pair. This sampling allows parents to transmit different samples of inheritance to each offspring. These samples even from the same parent may vary greatly and usually do as to the genes in each, although two samples from the same parent are almost always more alike than two samples from different individuals.[2]

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[2] The genetic make-up, or genotype, of an individual when only one pair of genes is considered may be homozygous dominant AA, heterozygous or hybrid Aa, or homozygous recessive aa. If dominance is complete the hybrid Aa cannot be distinguished from the homozygous AA, but the two do not breed alike. One transmits the A gene to each of its offspring, the other transmits the A gene to half of its offspring and the a gene to the other half. If dominance is less than complete the hybrid Aa would be intermediate between the unlike parents for the character determined by that pair of genes. Considering only one pair of genes, two kinds of reproductive cells or gametes A or a and three kinds of genotypes AA, Aa, and aa are possible. From matings involving Aa and Aa parents the offspring are expected to occur in the ratio 1AA, 2Aa, and 1aa. In case dominance is complete, AA and Aa individuals are indistinguishable outwardly and the ratio of phenotypes, that is the offspring that appear to be alike, would be 3 of the dominant type to 1 of the recessive type. If dominance is lacking, the ratio of phenotypes from a mating of Aa and Aa would be the same as their genotypes, i. e., 1AA, 2Aa, and 1aa. With 2 pairs of genes each possibility for the one to occur in combination with each possibility of the other permits four kinds of reproductive cells or gametes to be produced by a hybrid AaBb individual. The four kinds of gametes would be AB, Ab, aB, ab. Then there are nine possible combinations of genes in the offspring from matings of such individuals. Three pairs of genes permit 8 kinds of gametes and 27 kinds of genotypes. Now, since many pairs of genes are present in swine, perhaps hundreds or thousands, it is clear that the possibility of having all pairs homozygous in even one animal is extremely remote.

Expression of most characters is not wholly determined by one pair of genes, but several pairs are involved. Therefore, much variation in the expression of a character such as numbers of pigs in a litter, vitality of pigs and growth rate is expected. Expression of such characters is also influenced greatly by environment, seemingly much more than by heredity in many cases. Then there is the possibility that more than two kinds of allelic genes—such as A, A′, A″, a or

In about two decades following the rediscovery, in 1900, of the Mendelian principles some experimental effort was focused on exploring the Mendelism or hereditary behavior of specific characters in farm animals. Inheritance of color and the various patterns of color received much attention for a time. The number of pairs of genes involved in the inheritance of most characters, even of color, was underestimated by most students at that time. However, the complexity of the many types of interactions between genes controlling various characters began to be recognized.

As the gains made through the formation of breeds were being consolidated, both before and after 1900, a question often posed by farmers was: Which breed is best? Many farmers made observations and comparisons and several colleges and experiment stations conducted trials comparing various breeds. These comparisons did not answer all the questions as to the best breed, but they did indicate that the breeds differed in regard to various performance characters. No one breed was best in all respects. Much interest prevailed regarding the value of purebred or registered sires. Numerous experiments were conducted by experiment stations between 1890 and 1925 in which litters by purebred boars were compared with litters by non-purebred boars. Generally the comparisons were in favor of the purebred sires. Farmers were also asking questions regarding the best crosses and how the performance of purebreds compared with that of crosses.

Many experiment stations and hog producers compared crossbred litters with purebred litters. The results usually were in favor of the crosses but in most cases the differences were small. In recent trials "criss-crossing" of two breeds in rotation, and rotation of three or more breeds in crosses brought out not only differences in favor of first-cross litters but also advantages gained by use of crossbred sows as compared to pedigreed sows, both being bred to purebred boars.[3] But these interpretations were opposed by some investigators.[4]

The most suitable type of hog was a matter of controversy from the beginning of the breeds, perhaps long before. Earliest comparisons by experiment stations were between the "lard type" and "bacon type" breeds. Differences reported between the two were generally small,

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B, B′, B″, b—may occur in many of the series. Many such cases are already known in some species of both plants and animals. Thus the variations which are actually observed in the various characters are numerous because of the different combinations of genes and their nature as to dominance, lack of dominance, interactions between the various genes themselves, and the joint interactions of genes and the environment. In recent years it has often been suggested that in the case of some genes the hybrid combination may exceed either of the homozygous types in expression, i. e. the heterozygote may produce the most preferred type. These are some of the problems with which both investigators and breeders must work in trying to improve the breeding value of animals, and in trying to explain in terms of genetics what is actually seen in the animals or to deduce from the genetic laws better methods of breeding.

[3] Winters, L. M., Kiser, O. M., Jordan, P. S., and Peters, W. H. A SIX-YEAR'S STUDY OF CROSSBREEDING SWINE. Minn. Agr. Expt. Sta. Bul. 320. 1935.

Lush, J. L., Shearer, P. S., and Culbertson, C. C. CROSSBREEDING HOGS FOR PORK PRODUCTION. Iowa Agr. Expt. Sta. Bul. 380. 1939.

Robison, W. L. CROSSBREEDING FOR THE PRODUCTION OF MARKET HOGS. Ohio Agr. Expt. Sta. Bul. 675. 1948.

[4] Carroll, W. E., and Roberts, E. CROSSBREEDING IN SWINE: DOES IT OFFER AN EFFECTIVE METHOD FOR THE IMPROVEMENT OF MARKET HOGS? Ill. Agr. Expt. Sta. Bul. 489, 1942.

but three points of particular interest are evident: (1) The breeds differed in rate of growth and desirability of carcasses; (2) a higher percentage of first rate bacon carcasses could be expected from the bacon type, or from crosses of bacon type with lard type, than from the lard type breeds bred pure; (3) hogs of bacon type compared favorably in rate of growth and economy of gain with those of lard type up to weights of 200 or more pounds.

Within the lard type breeds, type has ranged from a small early-maturing excessively fat chuffy type to a large heavy-boned late maturing and rangy type. These variations led some years ago to the practice of designating three types: (1) small, (2) intermediate or medium, and (3) large. The three types were particularly distinct in the Poland China breed. Claims and counterclaims as to the merits of these three types were current for many years. Trials were conducted at several experiment stations beginning about 1917 to compare their performance. The trials at the Illinois, Indiana, Iowa, and Bureau of Animal Industry stations are of particular interest.[5]

Results from these trials differed in several respects but agreed generally on certain important points. The intermediate type demonstrated the most favorable combination of litter size, rate of growth, economy of gain, and desirability of carcasses. Some of the three types were fed to the same degree of finish in the Bureau of Animal Industry trials. In these trials the hogs graded Choice and were slaughtered at average live weights of 143, 214, and 252 pounds for the small, intermediate, and large types respectively.

Early Experiments With Inbreeding

Inbreeding played an important part in the success of the noted livestock breeders who laid the foundations of the various breeds. It was to a large extent by inbreeding selected animals that they fixed the type they desired and made animals increasingly able to transmit their qualities. But lowered fertility, increased difficulty in raising the young, and reduced size were associated with inbreeding. Accordingly inbreeding fell into disfavor.

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[5] Bull, Sleeter, and Longwell, J. H. SWINE TYPE STUDIES. II. TYPE IN SWINE AS RELATED TO QUALITY OF PORK. Ill. Agr. Expt. Sta. Bul. 322. 1929.

Carroll, W. E., Bull, Sleeter, Rice, J. B., and others. SWINE TYPE STUDIES. I. TYPE IN SWINE AS RELATED TO RATE AND ECONOMY OF GAIN. Ill. Agr. Expt. Sta. Bul. 321. 1929.

Culbertson, C. C., and Evvard, J. M. TYPE TEST STUDIES—TYPICAL LITTER COMPARISONS. Iowa Agr. Expt. Sta. Leaflet 106. 1924.

Hetzer, H. O., and Brier, G. W. EXTENT TO WHICH TYPE DIFFERENCES AMONG SWINE AFFECT LITTER SIZE. Amer. Soc. Anim. Prod. Proc. pp. 135–138. 1940.

Mitchell, H. H., and Hamilton, T. W. SWINE TYPE STUDIES. III. THE ENERGY AND PROTEIN REQUIREMENTS OF GROWING SWINE AND THE UTILIZATION OF FEED ENERGY IN GROWTH. Ill. Agr. Expt. Sta. Bul. 323. 1929.

Scott, E. L. THE INFLUENCE OF THE GROWTH AND FATTENING PROCESSES ON THE QUANTITY AND QUALITY OF MEAT YIELDED BY SWINE. Ind. Agr. Expt. Sta. Bul. 340. 1930.

Zeller, J. H. SWINE TYPE AS A FACTOR IN PORK PRODUCTION. Amer. Soc. Anim. Prod. Proc. pp. 279–283. 1940.

Zeller, J. H., and Hetzer, H. O. INFLUENCE OF TYPE OF HOG ON PRODUCTION EFFICIENCY. U. S. Dept. Agr. Cir. 698. 1944.

The Mendelian discoveries, however, offer explanation of the effects attributed to inbreeding.[6] It became clear at once that hidden recessive characters are carried by many animals, and that these come into expression only when they become homozygous; i. e., they inherit them from both parents. The chances of carrying the same hidden recessive genes are greater in relatives than in unrelated animals. In most cases the dominant character is the progressive one and the recessive the retrogressive, often lacking in vigor. Thus it became evident that matings of closely related animals frequently bring to light hidden recessive characters.

The Mendelian mechanism soon became recognized as the universal mechanism of heredity under sexual reproduction. Two views developed from studies of inbreeding and crossing. First that it should be possible to isolate inbred lines pure in all genes conducive to vigor and hence that these lines would be equal or superior to crosses. Second that there is a favorable interaction between unlike genes which causes hybrids or crosses to show some degree of superiority beyond what can be achieved by pure types.

An extensive investigation of the effects of inbreeding in guinea pigs was initiated in 1906 by the Bureau of Animal Industry.[7] A start was made with 35 families or lines, but only 23 of these continued in the experiments. Matings were between brothers and sisters in all but one family, parent and offspring matings were practiced in that one. The best individuals in the litter were selected for breeders in all cases. Comparison of the inbreds with a control stock raised under similar conditions without inbreeding showed that on the average the inbreds suffered a decline in vigor in all characteristics measured, although this varied from line to line and from character to character. The decline was most marked in the frequency and size of litter. Families became differentiated in respect to color and a number of other characters. The bringing to light and fixing of different characters in different families so that definite differences between families or lines become conspicuous is probably one of the most important results from inbreeding.

In the later years of the experiments crosses were made between several families. Crosses between inbred families resulted in a marked improvement over both parental stocks in every respect. Crossbred females produced a distinctly larger percentage of living young than

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[6] The principal effect of inbreeding is the increased probability of an individual getting similar genes from its sire and dam. Therefore, inbreeding increases the chances of getting an increase in the homozygous pairs of genes, AA or aa, as contrasted to the Aa (or heterozygous pairs). Wright's method of calculating coefficients, which is used generally to express the degree of inbreeding resulting from a particular mating, helped in understanding changes resulting from inbreeding. The coefficient starts at zero for random mating and increases to 1.0 as the probable proportion of heterozygous pairs of genes decreases. (Wright, Sewall, 1922. Coefficients of Inbreeding and Relationship. Amer. Nat. 56: 330–338.) Accordingly a coefficient of 0.25, or 25 percent, means that the number of heterozygous pairs of genes has been reduced by 25 percent from the level at which it was in a particular group or population when the inbreeding began.

[7] Wright, Sewall. THE EFFECTS OF INBREEDING AND CROSSBREEDING ON GUINEA PIGS. U. S. Dept. Agr. Buls. 1090 (Parts I and II) and 1121 (Part 3), 1922. (Out of print; may be consulted in libraries.)

females of the best of the inbred families which entered into their composition. Wright suggested that these results point the way to an important application of inbreeding in the improvement of livestock. By starting a large number of inbred lines important hereditary differences would be brought to light and fixed. Selections could be made between lines. Crosses between selected lines should give full recovery of whatever vigor was lost by inbreeding, and some crosses could be expected to show a combination of desired characters distinctly superior to the original stock.

An inbreeding experiment was initiated in 1909 with rats at the Wistar Institute of Anatomy and Biology.[8] In this experiment a strain of rats (2 lines beginning with the 7th generation) was inbred, brother mated with sister for 25 generations, while intense selection was practiced. Not only was the vigor maintained but the inbreds actually surpassed the random bred control stock in size and fertility. This result was attributed to the selection practiced.

Early Inbreeding Experiments With Swine

The Delaware Station started an inbreeding trial with Berkshire and Yorkshire swine in 1908, which was continued for 10 years.[9] Some double matings of Berkshire sows were made using Berkshire and Yorkshire boars. Later a Chester White boar was used instead of the Yorkshire. Both inbred and crossbred pigs were obtained in the same litter by this practice. Mortality was greater among the inbred than among the crossbred pigs, and the certainty of conception and size of litters were reduced in the course of the trials. An experiment with brother and sister matings in a herd of Berkshires was started at the California station in 1922. In 1933 it was reported that no noticeable loss in litter size or in vigor of pigs was evident.[10] Pigs of the inbred litters were more uniform than those in outbred litters. Litter size farrowed held up rather well until 1947 when an outcross was made. The outcross was made because it had become difficult to raise the inbred pigs.[11]

The Bureau of Animal Industry initiated an inbreeding experiment with swine in 1922 to develop inbred lines in the Chester White, Tamworth and Poland China breeds for use in genetic and nongenetic

[8] King, Helen D. 1918. Studies on Inbreeding:

I. THE EFFECTS OF INBREEDING ON THE GROWTH AND VARIABILITY IN THE BODY WEIGHT OF THE ALBINO RAT. Jour. Expt. Zool. 26(1): 1–54.

II. THE EFFECTS OF INBREEDING ON THE FERTILITY AND ON THE CONSTITUTIONAL VIGOR OF THE ALBINO RAT. Jour. Expt. Zool. 26(2): 335–378.

III. THE EFFECTS OF INBREEDING WITH SELECTION ON THE SEX RATIO OF THE ALBINO RAT. Jour. Expt. Zool. 27(1): 1–36.

IV. A FURTHER STUDY OF THE EFFECTS OF INBREEDING ON THE GROWTH AND VARIABILITY IN THE BODY WEIGHT OF THE ALBINO RAT. Jour. Expt. Zool. 29(1): 71–111. 1919.

[9] Hays, F. A. INBREEDING ANIMALS. Delaware Agr. Expt. Sta. Bul. 123. 1919.

[10] Hughes, E. H. INBREEDING BERKSHIRE SWINE. Jour. Hered. 24: 199–203. 1933.

[11] Information to author from Prof. Hubert Heitman, Jr., Univ. Calif.

experiments.[12] It was planned to use only full brother and sister matings. That plan was followed in the Poland China and Tamworth stock, but the plan was changed in case of the Chester White to include matings of animals less closely related than brothers and sisters. Poland China lines failed after the second generation owing to an excess proportion of males in the inbred litters, a decrease in litter size, and heavy losses up to weaning. Two out of five Tamworth lines survived to the fifth generation and then failed for lack of fecundity. After 17 years of inbreeding the Chester White line showed a small decline in litter size. Selections were based on conformation, vigor, litter size, and rate of growth. One of the Chester White lines has been continued and is now being used in trials at the Wisconsin station.

Seven inbred lines of Poland China were started at the Southeast Experiment Station, Waseca, Minn. beginning in 1924.[13] Three were lost in the first and one in the third generation. The three remaining lines were carried successfully through the fifth, sixth, and eighth generations respectively without marked loss of vigor. After the eighth generation one of the lines was selected for further trial. The stock was culled closely and crosses made between two of its sublines.[14] Subsequently it has been inbred more slowly than formerly. The inbreeding is now about 80 percent and the line is being used in various crossing trials at the Minnesota station.

An experimental study of the consequences of inbreeding Poland China was started at the Iowa station in 1921 with brother and sister matings.[15] Because of infertility and irregular breeding the matings were discontinued in 1925. A new experiment was started in 1930 in which intense, mild, and very slight inbreeding could be compared. This experiment has been continued to the present time.

A trial was started in 1923 at the Oklahoma station with the Duroc breed.[16] Half-brother × half-sister matings were practiced. Inbreeding averaged about 46 percent in the eighth generation. Although there was some positive selection, litter size, vigor, and growth rate declined as inbreeding progressed, in comparison with a noninbred control herd. This line has been discontinued.

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[12] McPhee, Hugh C., Russell, E. Z., and Zeller, J. H. AN INBREEDING EXPERIMENT WITH POLAND CHINA SWINE. Jour. Hered. 22: 393–403. 1931. (Also in Report of the Chief of the Bureau of Animal Industry, 1934.)

Hetzer, H. O., Lambert, W. V., and Zeller, J. H. INFLUENCE OF INBREEDING AND OTHER FACTORS IN CHESTER WHITE SWINE. U. S. Dept. Agr. Cir. 570. 1940.

Hetzer, H. O., Hankins, O. G., and Zeller, J. H. PERFORMANCE OF CROSSES BETWEEN SIX INBREED LINES OF SWINE. U. S. Dept. Agr. Cir. 893. 1951.

[13] Hodgson, R. E., AN EIGHT GENERATION EXPERIMENT IN INBREEDING SWINE. Jour. Hered. 26: 209–217. 1935.

[14] Winters, L. M., Comstock, R. E., Hodgson, R. E., and others. EXPERIMENTS WITH INBREEDING SWINE AND SHEEP. Minn. Agr. Expt. Sta. Bul. 364. 1943.

[15] Iowa Agr. Expt. Sta. Ann. Rpts. 1921–1926 and 1948.

[16] Willham, O. S. and Craft, W. A., AN EXPERIMENTAL STUDY OF INBREEDING AND OUTBREEDING SWINE. Okla. Agr. Expt. Sta. Tech. Bul. 7. 1939.

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A successful show herd of Berkshires was developed from one boar and one sow at the South Carolina station.[17] It was reported later, however, that weaning weights and growth rate declined as inbreeding increased. New blood was introduced by the purchase of two boars in 1932. One of these boars crossed satisfactorily with the herd. But the herd was lost because of diseases believed to have been picked up on the show circuit in 1936 and 1937.

The small numbers used and the plans of matings practiced in the early experiments with inbreeding swine limited opportunities for selection. Most of the results were negative as to outcome. But there was some encouragement from these trials. Results obtained with the guinea pigs in the Bureau of Animal Industry and with rats at the Wistar Institute, together with the results being obtained with hybrid corn in the early 1930's, stimulated further interest among farmers and experiment stations in regard to further use of inbreeding in the case of swine.

Wright's analysis of the theoretical consequences to be expected from relatively mild inbreeding indicated that selection could offset much of the detrimental effects of inbreeding.[18] It seemed possible, therefore, to produce inbred lines of high average merit by following moderate inbreeding, even though that might not be so with such intense inbreeding as had been tried. Furthermore, it seemed desirable that possibilities with crosses of inbred lines both within the pure breeds and between the breeds should be investigated.

Improvements in swine through the years by breeders of the pure breeds were recognized, but thoughtful breeders and hog producers expressed concern as to the danger of becoming complacent with regard to further advances. Evidence accumulated from both plants and animals indicated that "hybrid vigor" obtained through crossing of breeds or crossing of inbred lines is important with respect to some of the major performance characters in species such as swine.

Information gained from experience and genetic experiments with plants and animals, including poultry, indicated that the most important problem was that of investigating as thoroughly as possible the consequences and uses of inbreeding and of crossing inbred lines. It was realized that such a program was a difficult one. Development of new methods, new techniques, and possibly new principles might be necessary. Large numbers of animals and facilities for handling them would be required. Also the amount of labor and technically trained personnel necessary would be large.

The experimental problems recognized were developing means of improving the established pure breeds so that each would excel crosses in respect to performance characters; forming new breeds with new combinations of characters which would be superior to the old breeds, and finding means of using breeds so that further increases in performance could be obtained through crossing.

General recognition of the problems and the need for cooperative effort because extensive facilities were necessary for such research led

[17] Godbey, E. G. and Starkey, L. V. A GENETIC STUDY OF THE EFFECTS OF INTENSIVELY INBREEDING BERKSHIRE SWINE. S. C. Agr. Expt. Sta. Ann. Repts. 1926 and 1932, and information to the author from Prof. E. G. Godbey, Clemson College and S. C. Agr. Expt. Sta.

[18] Wright, Sewall. SYSTEMS OF MATING. Genetics 6: 111–178. 1921.

to the establishment of the Regional Swine Breeding Laboratory in 1937 with headquarters at Ames, Iowa. The program was organized on a broad basis with all of the cooperating stations having similar objectives but with each having latitude to investigate problems in which it was most interested and best prepared to undertake. Research undertaken has been planned and coordinated through conferences of representatives of each of the cooperating States and the U. S. Department of Agriculture.

OBJECTIVES

The principal objectives of the program are to discover, develop, and test procedures of breeding and selection which may be used by hog producers to speed the improvement of hogs in performance; to investigate precisely the usefulness of inbred lines for improving breeding value of the pure breeds and for use in pork production; to enlarge knowledge concerning the genetic effects of inbreeding, and the inheritance of characters; and to evaluate and demonstrate application of such knowledge in swine breeding. Points emphasized in the investigations include productiveness of sows, vitality of pigs, growth rate, economy of gains, and desirability of carcasses.

SOURCE OF MATERIAL

Data and reports of research on which this report is based are from 10 projects in progress at cooperating stations.[19] The data include 14,100 litters of pigs. These include 7 old breeds, 2 new ones, and 5 crossbred foundations on trial. The present report is a summary of progress of the research to the present time.

A list of the publications from the projects is presented at the end of the report. These are arranged alphabetically according to the name of the senior author and are numbered consecutively. Numbers are used throughout the text in referring specifically to publications cited. Those not cited are included for the convenience of readers who may desire them.

FACILITIES, EQUIPMENT, AND PERSONNEL

The land, permanent buildings, and animals required for investigations are provided by the cooperating State stations. Technical personnel, clerical help, labor, and equipment needed in the various projects are provided jointly by the cooperating agencies. Approximately 1,500 breeding animals are being used in the experiments in progress.

RESULTS

Developing Inbred Lines

Stock was obtained as foundation material for inbred lines from many sources. In some cases herds on hand at a station, on which

[19] Nine of these projects are organized on a formal basis and receive some Federal funds. One station, Ohio, has cooperated informally without receiving Federal aid and has supplied some data included in this report.

records were available for several years, were used to start one or more lines. Each station has obtained stock from good herds of purebreds for the different breeds represented in the experiments. Stock was selected from herds in various sections of the country and with differing pedigree backgrounds.

The breeds, crossbred foundations, and the number of lines started at each of the stations are indicated in table 1. Many lines were dropped after the first 1 or 2 years because of low fertility or poor performance otherwise. Most of the stations have crossed two or more lines of the same breed at various times and started a new line from such crosses. In many of these cases the lines used in a cross were no longer retained as lines. Lines were culled on the basis of performance of the lines themselves and of their performance in crosses with other lines. Such culling of lines is practiced more or less continuously in each of the projects. It seemed that there should be possibilities for extending improvement through inbreeding and selection, particularly if inbreeding were increased at a moderate rate with selections based on performance.

To test this idea some lines have been inbred slowly and with numbers which were thought to be large enough to permit selection based on performance to develop superior stock. Other lines have been inbred more rapidly. Some lines have been inbred by following definite plans of mating. But in other lines matings were based on performance with little attention to rate of inbreeding. In those cases full freedom could be exercised in making the matings each season, the only restriction being that imposed by breeding within a line. Accordingly, methods of inbreeding have differed at different stations, and in some instances for different lines at the same station.

Distinctly different plans of inbreeding have been followed in the Iowa and Minnesota projects. It was planned in the Iowa project to investigate inbreeding at three different rates for the purpose of forming lines (*29*, *57*).[20] First, one line of Poland Chinas, started in 1930 and bred as a closed herd using 4 boars and about 40 sows per year, became part of the cooperative effort in 1937. Inbreeding in such manner increases approximately 3 to 4 percent per generation. Second, three lines were started by using 2 sires and 20 sows per line. The increase in inbreeding should be about 6 to 7 percent per generation in these. Third, eight lines were started with 1 sire and 10 sows in each line, inbreeding was expected to increase 12 to 13 percent per generation by that practice. A line of Danish Landrace, which descended entirely from 2 boars and 3 sows imported in 1934, was continued after 1937 as a 2-sire line.

In the Minnesota project (*93*) the inbreeding program was flexible, the inbreeding was not to be advanced at any fixed rate or by any given procedure such as half-brother × half-sister matings. Therefore, more freedom in selections and matings was permitted than in a fixed program. It was planned, however, to advance the inbreeding as rapidly as possible without sacrificing performance. To accomplish the latter, matings with a rather wide range in degree of closeness have been made in each line. As related earlier, one line of Poland China started in 1924, at the Minnesota station and continued for 8 generations with brother × sister matings, was continued in the

[20] Italic numbers in parentheses refer to literature cited, page 46.

TABLE 1.—*Breeds, crossbred foundations, and lines started at the stations*

Breeds and crossbred foundations	Stations and number of lines										
	Illinois	Indiana	Iowa	Minnesota	Missouri	Nebraska	Ohio	Oklahoma	South Dakota	Wisconsin	Total
Berkshire		1									1
Chester White		4	14							6	24
Duroc			1		1	12	2	18	1		35
Hampshire	2				2				1		5
Landrace			2		1						3
Poland China			12	16	4				2		34
Yorkshire		1							1	1	3
Minnesota #1 [1]				1							1
Minnesota #2 [2]				1							1
Chester White-Yorkshire										1	1
Landrace-Duroc		1									1
Landrace-Poland China			1								1
Landrace-Duroc-Berkshire-Yorkshire						1					1
Hampshire-Poland China-Duroc-Landrace [3]									1		1
Total	2	7	30	18	8	13	2	18	6	8	112

[1] Based on a Landrace×Tamworth cross.
[2] Based on a cross of Canadian Yorkshire and 2 inbred lines of Poland China.
[3] This stock is being used in comparing rotation linecrossing of breeds with rotation crossing of lines within the Poland China breed. A breed is not being formed from this cross.

project by converging two sublines of the stock in 1937. Since that time the inbreeding has been increased rather slowly, but the inbreeding is about 80 percent at the present time. Several new lines of Poland China have been developed at the different Minnesota branch stations following the breeding plan mentioned. Inbreeding of lines retained ranges between 25 and 50 percent. Details relating to these have been reported (*76*), (*93*), (*96*).

Two lines were formed from crossbred foundations in the Minnesota project. Methods used and results obtained have been reported by Winters and coworkers (*12*), (*68*), (*92*), (*93*), (*96*). The first came from crossing the Danish Landrace and Tamworth breeds. The method used is essentially the same as has been used successfully during recent years by plant breeders, and known as the pedigree method. The objects were: (1) To combine in a single strain a maximum of the desirable characters of both parental breeds; and (2) to induce the recombination of genetic factors which will result in producing new and desirable characters not found in either parent. The steps used were: (1) The selection of two breeds (Landrace and Tamworth) believed to possess characteristics desired and to be rather widely separated genetically; (2) the selection of foundation animals with as much individual excellence and background of performance as was possible; (3) breeding from within a closed herd; and (4) rigorous selection from the outset for factors affecting economy of production. In this case the objective was to combine as much as possible of the length of body and plumpness of ham of the Landrace with the red color, prolificacy, and milking ability of the Tamworth, and simultaneously to bring through recombination of genes an accumulation of other desirable characteristics of the two breeds. The three items of performance given most weight in selections were fertility, rate of gain from weaning to 200 pounds, and economy of gain. The herd has performed at a high level for these traits and the quality of carcasses has been high. It is estimated that the genetic composition of the herd is approximately 48 percent Landrace and 52 percent Tamworth. This line was designated a new breed in 1946 and named Minnesota No. 1.

The second Minnesota line from a crossbred foundation was established from a cross of Canadian Yorkshire and two inbred lines of Poland China stock at the Minnesota station. It is black with white spots. Another lean type of hog, efficient in production, that would cross well with the Minnesota No. 1 was desired. The Poland China lines used had a good record for rate and economy of gain and produced satisfactory carcasses. But their fertility was not high and the sows were poor milkers. The Yorkshire was used for improving fertility and milking ability of the sows and to extend improvement of carcasses. Approximately the same procedures of selection were followed in this line as in the No. 1, except that some selection for superficial characters differing from the No. 1 was practiced, when that could be done without sacrificing performance. It was believed that advantages in crossing would be increased with two lines possessing many economic characters in common but differing as much as possible in superficial traits. Results obtained in crosses of this line with No. 1 support that view. This line was designated a new breed, Minnesota No. 2, in 1948. Calculations indicate that about 40 percent

of the inheritance came from the Yorkshire and 60 percent from the Poland China.

There were 725 herds of Minnesota No. 1 as of August 1952, comprising 15,239 registered animals. Approximately 90 herds of Minnesota No. 2 have been established and 2,173 animals have been registered. These two breeds are registered by the Inbred Livestock Registry Association, St. Paul, Minn.

In other projects the rate of inbreeding in different lines has varied, and generally the practice has been somewhat similar to that followed in the Minnesota project. Several of the stations during the last few years have obtained from various purebred herds small groups made up of a boar and 2 to 4 littermate sisters. These have been inbred closely for two generations to determine how they reacted to inbreeding. Most of these groups have failed. Those retained have been expanded, and are being tested further as to their merits as lines and for use in line crosses.

The Indiana, Iowa, Nebraska, South Dakota, and Wisconsin stations each have a line from a crossbred foundation under study in addition to lines within pure breeds.

Problems Relating to Selection

First of all most of the effort in selection has been devoted to size of litter farrowed and weaned, rate of growth, economy of gain, conformation, and desirability of carcasses, but several other problems with regard to selection have been studied.

Measuring or Evaluating Performance Characters

Methods of measuring the characters have differed between stations in some respects, but similar records have been taken at each station on some of the characters.

In some projects 4 pigs from selected litters are fed from weaning to weights of 200 to 225 pounds to get records on growth rate and economy of gain for various breeding groups. A plan of feeding selected litters separately in pasture lots was initiated in the Minnesota project. This plan is followed to some extent at other stations.

Carcass data are obtained on samples of pigs from the various breeding groups. Records taken on carcasses have differed in many respects at different stations, but on certain items of the carcasses the same procedures were followed at each station. These data have served to indicate the carcass characteristics of the inbred lines, line crosses, and control groups, and for appraising differences between such groups. Methods of evaluating carcasses have been investigated also.

For several years animals in most of the projects were scored individually when they ranged from about 200 to 225 pounds in weight or at 5 to 6 months of age. Scoring was done by a committee of 2 to 5 judges. The scoring scheme rated the pigs for general vigor, length of body, quality, details of conformation, animal as a whole, and market grade. A scale ranging from 1 to 9 for each character was used. These records were studied with respect to agreement between judges, and to relationship of the ratings and performance of the pigs. A relatively high degree of agreement prevailed among the men scoring the same pig, and the scores reflected differences in the over-all ap-

pearance of the pigs. Some items contributed consistently more to the total score than others, and some were more closely correlated than others. Scores for quality and length of body were nearly independent of each other and of the other four items. Each of the items was correlated with weight of the pigs. Total score was highly correlated with weight of the pigs. But the relationship to over-all performance proved to be low. This scheme of scoring was largely discontinued, but some plan of scoring or rating individuals at weaning or later is practiced in some projects.

A scheme of describing nine items of conformation was tried for the purpose of studying the relationships between the items, and performance of the pigs. It consisted of drawings on a chart with a descriptive scale ranging from 1 to 9 for each item. Items included were: type of head, smoothness of shoulder, arch of back, slope of rump, length of legs, depth of body, shape or plumpness of ham, spring of ribs, and width of body. These items proved to have little value in selecting for performance.

The relationship between scores used for rating pigs at different ages prior to final rating was investigated (*97*). Gilts were scored at 112 and 180 days of age, or at 200 pounds; boars were scored at 112, 140 and 180 days, or at 200 pounds. Correlations between the 112-day ratings and final score for gilts were significant and relatively high, but the early scores had low value for predicting final scores. In the case of boars predictive value of the early scores was less than for the gilts. The results show that both boars and gilts often change widely during their development with regard to conformation, particularly boars. Further, these and other results indicate differing patterns of development for groups of different breeding. The correlations and predictive values obtained emphasize the unreliability of early selection of boars on a basis of their appearance, if ratings at about 200 pounds' weight represent their real desirability. Another study bearing on the same problem emphasizes that pigs change in form as they grow, and that these changes are subject both to genetic and environmental causes. It was suggested, therefore, that swine improvement in terms of performance characters would be more rapid if conformation were considered only at market weight and the attention given to type at other ages was shifted to performance (*16*).

Methods Used in Selection

Four plans of selection were initiated. These were at the Iowa, Minnesota, Wisconsin, and Illinois stations.

First Method.—The plan being used in the Iowa project involves a selection index [21] which is based on studies by Hazel (*41*), and by Lush and Molln (*58*).

[21] The index, $I=[.65W+P+C]\ (1.0-a)$. When W=154-day weight; P=productivity of dam; C=sib credits; a=penalty for defects. Sib credits are positive or negative allowances made for deviations from a standard of 140 pounds for 154-day weight per pig. For example, each pig in a litter which averages 150 pounds per pig would receive +4 for sib credits, even if some of the pigs weighed less than 140 pounds. Similarly each pig of a litter which averages 130 pounds per pig would receive —4 for sib credits. Penalties reduce the index 10 percent for the occurrence of any one of the following defects: cryptorchidism, hernia, blindness, and atresia ani. Should a pig show more than one of these defects the penalty would be 10 percent for each.

Productivity rating of dams is calculated as deviations of the dams from a standard for age, number of litters, number of pigs farrowed, number of pigs, and weight of litter at 21 and 56 days. Weights of litters at both 21 and 56 days are not regarded as necessary. The 56-day weights are slightly superior to 21-day weights (*69*). Weights taken a few days before or after 56 days are adjusted to a 56-day basis.[22]

Pigs are weighed twice for determining weight at 154 days, first about a week before, and second about a week after 154 days. These weights are adjusted to a 154-day basis and averaged.[23]

Through use of the index the herd is divided into high, medium, and low index groups. The low group usually is culled without further consideration. The high and middle index groups are looked over carefully for animals showing defects such as crooked legs, defective pasterns, and seriously undesirable body conformation. These are culled, insofar as possible, and almost without reference to the index.

Second method.—In the Minnesota project selections are based on five production traits. These are: (1) number of pigs farrowed alive, (2) number of pigs weaned and weight per litter, (3) growth rate from weaning to 200 pounds, (4) economy of gain, and (5) conformation. The method of selecting breeding stock is described in Minnesota Station Bulletin No. 364 (*93*). More litters are farrowed than can be tested. Therefore, first selections are made at weaning. These are based largely on size of litter which emphasizes number farrowed, number and weight of pigs weaned. Litters thus selected are fed out separately in pasture lots to obtain records on growth rate and economy of gain to 200 pounds. Pigs are rated individually by scoring when they finish the test. Scores are based on eye appraisals of vigor and thrift, quality, length of body, conformation, animal as a whole, and market grade. Each item is rated on a scale ranging from 1 to 9. Data obtained on each litter are recorded on summary sheets, a separate sheet being used for each litter. Summary sheets are spread on a table so that data on the various items can be observed and tentative choices made easily. After selections have been made on a basis of the records on litters and individuals within litters each pig is inspected individually for serious defects, such as light hams and bad

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[22] $Y=Z\frac{41}{x-15}$: when Y=adjusted weight, Z=actual weight when weighed, and x=age in days when weighed.

Example: 59-day weight=39 pounds.

$$\text{56-day weight}=39\frac{41}{59-15}=36.3 \text{ pounds.}$$

[23] Weights are adjusted to 154 days by use of the formula:

$$W=Z\frac{142.5}{.0032143\ X^2+.58X-23}$$

when W=adjusted weight, Z=actual weight when weighed, and X=age in days.

Example: 160 day weight=180 pounds.

$$\text{154 day weight}=180\frac{142.5}{(.0032143)\,25600+89.3-23}=168.7.$$

Tables of conversion factors for adjusting weights to 56 and 154 days can be prepared by use of these formulae.

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legs. Pigs showing a serious defect usually are culled, although their record otherwise may be good. Feed records are adjusted for each litter to a standard weaning weight of 33 pounds per pig, because of the relationship between weights of pigs at weaning and feed required for gains. Minnesota data show that feed required for 100 pounds of gain increases 0.8 pounds for each additional pound per pig at weaning. Accordingly, 0.8 pounds of feed per 100 pounds of gain are deducted for litters averaging 34 pounds per pig at weaning. Similarly 0.8 pounds of feed per 100 pounds gain are added for litters averaging 32 pounds at weaning.

Approximately 30 percent more gilts are saved than are wanted for farrowing. Therefore, some culling is practiced on a basis of the gilts settling, and some that may later appear unthrifty. Thus selection of sows is almost a continuous operation. Boars are selected in essentially the same manner as gilts, except that much smaller numbers are retained, which permits more emphasis on the performance of litter mates and on pedigree than in the case of gilts.

Third method.—The Wisconsin station in cooperation with farmers in the State, is testing the application of an indexing method for selecting pigs. The farmer supplies records for each litter which include date of farrowing, sex, identification number for each pig at birth, age of the dam, and weight of pigs at approximately 5 months of age. Index ratings are calculated at the station and supplied to the farmer when completed. Ratings are determined in the following manner:

One point is given for each pig in the litter up to 12. Because of high average mortality of pigs in litters of more than 12 pigs no points are given for pigs in excess of 12.

Two points are given for each pig raised to 5 months. Pigs sold before reaching 5 months of age are included.

Weights at 5 months are adjusted to a 154-day basis (weights are taken within 2 weeks of 154 days, and date of weighing recorded). Seven-tenths of a point is given for every pound over 75 pounds per pig.

Adjusted 5-month weights are totaled for each litter. The adjusted total for the litter is divided by 100. The result is the number of points to be given each pig for weight of the litter.

If a gilt farrows her first litter before she is 18 months old, 10 points are added to adjust the litter to a sow basis.

Fourth method.—Effectiveness of selection based on only one character, growth rate, has been tried on Hampshire swine in the Illinois project. Results for four generations have been reported (*51*). Selections were for rapid growth to 180 days in one line and for slow growth in the other line. The two lines were separating in growth rate but it seemed that slow growth was more easily obtained than rapid growth. Litter size declined in both lines (*32*). The yield of growth promoting hormones, substances obtained from the pituitary glands of 86 pigs of these two lines, indicated physiologic differences in lines, and the records of weight for age (*5*) seemed to confirm this.

Theoretical Studies Relating to Selection

Data from two projects, Iowa and Nebraska, were combined and studied with respect to selection for growth rate of pigs and performance of sows (*26*). It was concluded that in selecting for rate of growth, from 8 to 10 times as many boars and about 3 times as many

gilts, as are needed for breeding, should be kept after weaning until information is obtained on their growth rate. In selection for sow performance the results indicated that yearly progress should be greatest by culling most sows when the first litters are weaned, saving only the best one-third to one-half to produce a second litter 6 months later. But delaying the first culling until second litters are produced, then keeping one-fifth to one-fourth of the sows for a third litter should be about as effective as the preceding plan. Saving some of the best sows at second culling is suggested if they are superior to the gilts or to the younger sows which would be selected to replace them. Accuracy can be improved by basing selections on two litters rather than one and, if two litters are produced per year, this can be done with a minimum increase in average interval between generations. The results emphasize that the interval between generations should be kept as short as practical.

Records on the herds at stations in the region and from the Bureau of Animal Industry which were obtained over a period of years before the laboratory was started were pooled and the performance of groups of sows from litter to litter was analyzed (*58*). This is called repeatability. It is expressed as the fraction of the difference between single records of any two sows which will most likely occur between future records of the same two sows. Therefore, it measures the effectiveness of selecting sows for future performance. A figure of 0.16 was obtained for size of litter farrowed and weaned. Accordingly, if the gilts saved had averaged one more pig per litter in their first litter than the average of all gilts in the herd, the later litters of the gilts saved should average about one-sixth more pigs per litter than if no attention had been paid to size of the litters when deciding which gilts to keep for second litters. Similar results were obtained in later studies of other data (*48*, *73*).

Length of gestation also seems to be repeatable to some extent. The figure obtained from data in one project is 0.26 (*63*).

Theoretical possibilities relating to different practices in selection have been investigated. One of these studies (*44*) explored possibilities expected from three different plans of selection for several independent characters: (1) selection for one character at a time until it is improved, then selection for another character, (2) selection for a total score or index of net merit based on two or more characters, and (3) selection for two or more characters at the same time, using independent culling levels for each. For example, 8 pigs farrowed, 7 pigs weaned, and individual weights of 160 pounds at 5 months of age might be used as standards for gilt litters in the use of independent culling levels. The outcome of this study was that selection for one character at a time should be less efficient than either of the other methods. An index of net merit should be the most efficient method. But there are complications involved in evaluating each character properly and in calculating the index. The method of independent culling levels seems to be the most useful practice generally, of the three methods. It has the practical advantage of permitting selection for one or more characters when they are manifest, without waiting until other characters are expressed before first cullings are made. It does not involve complicated calculations.

Another theoretical study regarding problems in selection was made to compare the progress expected from mass or individual selection,

family selection, and from a combination of individual and family selection (*55*). In brief, individual selection is effective when a character is highly heritable. Family selection should be most helpful when the relationship between members of a family is high, and for characteristics which are only slightly heritable. There is advantage in family selection in cases of noticeable dominance or "nicking" effects. When members of a family tend to resemble each other because of being raised under good or under poor conditions, rather than because they have similar inheritance, effectiveness of the family in selection is reduced, and in extreme cases the family average should even be given negative emphasis. Importance of the records on a family increases as the family becomes larger. A combination of individual and family selection usually is the most effective practice. But in giving attention both to family performance and individual performance some compromise must be made on each.

Inbreeding tends to increase the resemblance between members of a family; their inheritance bcomes more nearly identical as inbreeding increases. Therefore, more emphasis should be placed on the family or line average as inbreeding increases and the individuals become more nearly alike genetically. Thus selection between highly inbred families or lines can be much more accurate than selection on individual performance alone. But such practice has limitations. First of all the families must be inbred enough to make such selection effective, seemingly 30 percent or more. If selected families are to be combined, a generation is necessary for crossing two or more selected lines or families before new lines or families can be started from the best crosses.

Progeny testing has been emphasized for many years in selecting breeding stock. Emphasis has been mainly on its accuracy as compared with the use of pedigree, individual performance, or averages of relatives, or families as an indicator of breeding value. It is accepted generally that progeny testing, when used properly, can increase the accuracy of selections. Furthermore, it is recognized that genetic progress expected from selection in a given period of time, based on progeny tests, may be influenced greatly by factors other than relative accuracy. Age of the animals when progeny test information can be obtained and rate of reproduction seem to be the most important factors in its usefulness. The problems inherent in progeny tests were explored on theoretical grounds to supply information needed in swine breeding experiments (*27*). The measure of effectiveness used was the average genetic improvement expected annually from early individual selection alone as compared with that expected from progeny tests.

A regular plan of progeny testing is unlikely to increase, and may reduce, progress unless (1) the information obtained becomes available early in the tested animal's lifetime, (2) the reproductive rate is low, and (3) the basis for making early selections is relatively inaccurate as compared to selection on progeny records. Improvement of most traits should be about maximum when selections are based partly on individual performance, and partly on line or family average and pedigree, so that the interval between generations can be kept about as short as possible.

Heritability of Characters

The extent to which variations in a particular character are heritable is one of the factors that limit the progress which may be made through selection. Performance characters are affected greatly by environment. The response to selection, therefore, is reduced according to environmental effects. To know something regarding the relative importance of heredity and environment with respect to the variations for a certain character it is necessary to have estimates of these influences. Methods of estimating the heritability of characters based on correlations between relatives have been used, but sparingly, for many years. Techniques for using these methods, and avoiding discrepancies in their interpretation have been discussed by Lush (*53*, *56*). Estimates of heritability are expressed as fractions. For example, 0.15, or 15 percent, means that the variations in regard to a certain character are only about 15 percent heritable.

Through application of these techniques to data obtained on swine produced at the various stations, project leaders and their coworkers have obtained estimates for the heritability of the performance characters which have been under selection.

1. Number of pigs and weight of litters.—Estimates obtained for heritability of the number of pigs farrowed per litter range from about 10 to 44 percent. Most of these are between 10 and 20 percent. Perhaps 15 to 17 percent for heritability of number farrowed would be a reasonable estimate, although some data indicate lower values (*58*, *73*).

Estimates of heritability of numbers of pigs weaned per litter range from about 15 to 32 percent (*8*, *20*). Estimates obtained for heritability of litter weight at weaning range from 7 to about 37 percent (*8*, *13*, *20*, *58*).

In one project, sows were classified as good, medium, and inferior on a basis of the litters raised. Their daughters were classified likewise as to the litters they produced (*82*). Daughters out of "good" dams rated as follows: Superior, 1.5 percent; good, 40.6 percent; medium, 29 percent; and inferior, 29 percent. Similarly daughters out of "medium" dams rated: good, 17.4 percent; medium, 52.2 percent; and inferior, 30.4 percent. Daughters of inferior dams rated: medium, 13.6 percent; and inferior, 86.4 percent.

2. Growth rate.—Growth rate of the pigs has been studied rather extensively with respect to heritability. Estimates ranging from approximately 17 to 40 percent were derived for the variations in weight of pigs at about 5 months of age (*6*, *22*, *84*). For variations in rate of gain from weaning to weights of 200 pounds, heritability seems to be higher than for gains from birth (*6*, *25*, *64*).

3. Economy of gain.—Estimates for heritability of economy of gain have been derived from data obtained at only two stations. These are approximately 25 and 57 percent (*22*, *25*). Data from the Minnesota project indicate improvement from selection for economy of gain in some inbred lines as shown in table 2 (*12*, *76*, *93*).

4. Scores.—An estimate of 20 percent for heritability of conformation based on scores of pigs at market weight was derived from records in one project (*75*).

The foregoing estimates relating to heritability may be too high. Some might be too low, but this seems unlikely. We do not know. It has been pointed out (*53*) that discrepancies in the estimates may arise from: (1) small samples of data, (2) correlation between variations caused by the environment, (3) the mating system differing from random more or less than calculated, and (4) the genotype or animal as a unit performing differently than is expected from the sum of the average of the separate effects of its total genes. The animal functions as a unit. Therefore, "hereditary" applied in a broad sense includes over-all performance. But the gene, not the whole animal, is the unit in transmission from parent to offspring.

5. *Hereditary defects*.—A condition similar to hemophilia was observed in some foundation animals of one line of Poland China in the Missouri project (*9*). The incidence of "bleeders" increased in the stock as inbreeding progressed. Selection against it was intensified but the trait persisted and finally the line was dropped. The most frequent areas of bleeding were the gums, lips, sinuses, cut about the nose and ears. Internal bleeding caused death in several animals. Afflicted boar pigs bled to death in 4 to 5 hours after castration. In general, severity of bleeding increased as affected animals became older. It was concluded that the bleeding was due to a recessive gene, not sex-linked as is the case in man, and that variations as to severity were caused by modifying genes. Evidence was obtained that "bleeders" occur in other breeds also.

The incidence of scrotal hernia in lines of the Iowa project during a 10-year period (1938–47) has been reported (*59*). The incidence of scrotal hernia among the 13 inbred lines ranged from 0 to 15.7 percent and averaged about 5 percent of all the boar pigs for the entire herd. It averaged 10 percent or more in three of the lines during the 10-year period. In 1938, 9 percent of the boar pigs in the spring farrowed stock showed scrotal hernia, in 1947, 6 percent. The incidence ranged by years from 2 to 9 percent. Although there was some selection against the trait, there probably was not any real change during the period except that the difference between lines in respect to the occurrence of hernia became definitely established.

An estimate of 15 percent for heritability of scrotal hernia was obtained. Also a maternal effect of 15 percent was found. Whether or not this large and unexpected maternal effect was genetic or environmental was not determined. It was suggested, however, that a breeder should practice strong selection against sows that produce herniated pigs.

Many other defects have been observed in lines of the various projects but the frequency of their occurrence has been low and the degree of heritability has not been calculated.

Selection Practiced

As mentioned earlier, in each of the projects attention has been focused on selection for size of litters farrowed and weaned, weaning weight of pigs and their growth rate, with some attention given to conformation, economy of gain, and desirability of carcasses. The extent to which records on feed and carcasses were used has varied greatly between the different stations because of the differing circum-

stances and limitations of one sort or another. Losses due to disease imposed limitations on selection in some seasons. For example, selected animals which reacted to tests for brucellosis and were removed from the breeding herds reduced the selection in some seasons. In some seasons, too, losses of pigs before weaning were severe, owing to "baby pig troubles." These may have reduced selection considerably. Cholera "breaks" both before and after weaning caused severe losses in one or more seasons in some projects. Such losses may have reduced the average of the selection differentials even in the lines with relatively large numbers. But these are problems which are met with by hog producers generally and, therefore, over the years affect the amount of selection that can be applied.

Results from the early experiments with inbreeding swine usually indicated a small amount of selection but these groups were small and the inbreeding was advanced rather rapidly in most of them. When projects in the Laboratory were started it was not known how much selection might be applied for performance traits. Data from these projects probably indicate approximately the selection that can be practiced generally for the characters listed. It seemed important, therefore, to determine the amount of selection actually practiced in the various lines. Analysis of the data indicate that positive selection has been practiced, but that not all of the opportunity for selection was exercised in some cases. Furthermore, the response of the performance characters to selection generally has been less than was expected on the basis of estimates for heritability of the characters and the selection applied.

Selection practiced for the various characters is expressed as the "selection differential." For example, if the pigs selected for breeding in a particular line were from litters which averaged 9.5 pigs per litter, and the average for the whole line was 8.5, then the selection differential would be one-half pig per litter because litter size is a character of the dam, rather than of the pigs in the litter, and the pigs selected get half their genes from their sire. The selection differentials for growth rate are based on individual weights at weaning and at 154 days, or on rate of gain from weaning to about 200 pounds. For example, if pigs of a particular line, adjusted either to a gilt or sow basis, selected at weaning averaged 38 pounds, and all of the pigs in that line averaged 35 pounds, the selection differential for weaning weight per pig would be 3 pounds; and if 154-day weights averaged 180 pounds for animals selected for breeding stock, and the average for all pigs in the line was 160 pounds, the selection differential would be 20 pounds; if the average of the pigs selected was 1.8 pounds for rate of daily gain from weaning to 200 pounds and the average for the line was 1.6 pounds, then the selection differential would be 0.2 of a pound.

When the effective degree of heritability and the selection differential for a character are known, the progress expected per generation can be estimated. The progress should be the product of these. For example, if the heritability of number of pigs per litter as a measure of the dam's prolificacy is 0.15 and the selection differential is 0.80 in a herd, litter size should increase about 0.12 pigs per generation ($.15 \times .80$). Progress to be expected can be calculated in a similar manner for other characters.

Results from three projects, Illinois, Iowa, and Minnesota are especially interesting in regard to selection practiced because different methods were followed with respect both to inbreeding and to selection. These are discussed first; results from pooling data of several stations are presented later in this report. First of all it is of interest that there was some selection for litter size and litter weight at the Illinois station in both the rapid and the slow gaining lines even though only weight at 154 or 180 days was considered deliberately in making the selections. This happened simply because more pigs were available for selection in the larger litters. Selection differentials for litter size at birth and at weaning are shown in the top two lines of table 3.

Selection practiced in the Poland China lines at the Iowa station is indicated in figure 1. It is of interest that about the same amount

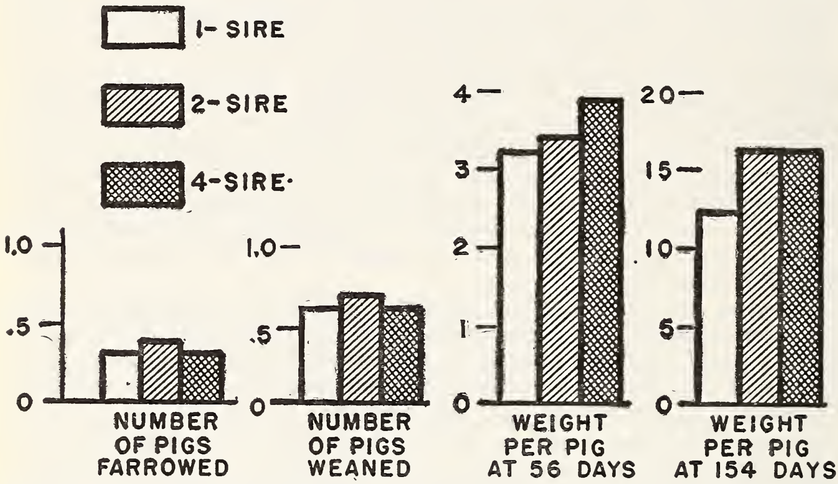

FIGURE 1.—Annual selection differentials for number of pigs farrowed and weaned per litter, and for weight per pig at 56 and 154 days in Poland China inbred lines at the Iowa station. (From Kottman (*50*).)

of selection was practiced in each of the groups for litter size, although the rate of inbreeding and the number of animals for each group differed. However, selection for weight per pig both at 56 and 154 days was greater in the 2- and 4-sire lines than in the 1-sire lines. Data on all of the Poland China lines in the Iowa project were combined in calculating the selection differentials for inclusion and are shown in the Iowa line in table 3.

Calculations covering selection practiced, changes which occurred, and changes expected in six lines at the Minnesota station are shown in table 2. The results expected and the actual results obtained are compared. The expected changes were calculated as indicated at the bottom of the table. Records for numbers of pigs born alive and for numbers weaned per litter were adjusted so that they could be treated as gilt litters.

TABLE 2.—*Results from selection in the Minnesota Station project, actual changes for the characters compared with expected annual genetic changes* [1]

Item	Breeding					
	Minnesota 1 1938–48	Minnesota 2 1942–48	Poland China inbred lines: V 1937–49	W. L. 1937–43	B. S. 1943–50	A 1943–49
Average annual selection differentials for number born alive	0. 73	0. 48	0. 95	0. 84	0. 33	0. 90
Average changes: Actual	—. 037	—. 183	—. 014	. 010	. 010	—. 006
Average changes: Expected	—. 041	—. 058	—. 027	—. 089	—. 149	—. 009
Average annual selection differentials for number weaned	. 81	1. 14	----------	1. 03	. 48	. 57
Average changes: Actual	—. 26	—. 155	—. 030	—. 141	. 016	—. 001
Average changes: Expected	—. 291	—. 208	—. 291	—. 458	—. 565	—. 294
Average annual selection differentials for 154-day weight	15. 1	10. 2	17. 65	19. 43	19. 48	14. 66
Average changes: Actual	—1. 278	. 826	. 040	. 306	. 562	. 485
Average changes: Expected	—. 335	—2. 824	—. 096	—. 813	—1. 023	—. 130
Average annual selection differentials for rate of gain (Weaning to 200 lbs.)	. 13	. 06	. 17	. 21	. 16	. 11
Average changes: Actual	—. 012	. 004	. 001	. 003	. 005	. 005
Average changes: Expected	. 005	—. 029	. 014	. 015	. 007	. 008
Average annual selection differentials for economical gain, lbs	—8. 1	—. 60	—1. 8	----------	----------	—3. 13
Average changes: Actual	1. 92	. 59	. 21	----------	----------	—. 025
Average changes: Expected	3. 13	—. 51	1. 22	----------	----------	2. 085
Average selection differentials for body scores	. 61	. 22	. 70	. 78	. 68	. 58
Average changes: Actual	. 017	. 117	. 011	. 032	. 028	. 016
Average changes: Expected	. 086	. 079	. 08	. 08	. 083	. 069

[1] Expected annual genetic change $= \frac{\text{Selection differential} \times \text{heritability of the character}}{\text{Generation interval}}$ — Decline from the inbreeding.

Data supplied by Winters and associates.

241687°—53——4

TABLE 3.—*Annual selection differentials for various characters*

Station	Litter size		Total litter weight weaned	Individual weight		Selection index [1]	Inbreeding	
	At birth	At weaning		At weaning	At 154 days		Dam	Individual
	Number	*Number*	*Pounds*	*Pounds*	*Pounds*		*Percent*	*Percent*
Illinois:								
Rapid line	0.36	0.60	17.9	3.92	17.2	28.1	0.14	−.12
Slow line	.24	.63	12.1	−1.22	−19.3	−9.6	−.03	−.22
Indiana	.34	.66	26.8	3.38	15.3	25.4	−.81	−2.28
Iowa	.30	.63	21.9	3.42	14.9	27.0	−1.27	−1.34
Missouri	.27	.47	16.8	3.72	15.5	25.0	−.23	−2.00
Nebraska	.36	.70	24.2	3.97	14.2	27.6	−.70	−.47
Oklahoma	.46	.79	23.5	3.84	15.8	30.2		−.96
Averages [2]	0.34	0.65	22.3	3.64	14.9	27.4	−1.48	−1.13

[1] Index$=2\left(N_0+2N_{56}+\frac{T56}{15}\right)+W_{154}$, where N_0, N_{56}, and T_{56} are the dam's litter size at birth and weaning and her total litter weight at weaning, respectively, and W_{154} is the pig's own weight at 154 days.

[2] Each station weighted by total number of line-season groups, omitting the Illinois "slow" line.

Data from six projects (Dickerson *et al* (*23*))

Data on economy of gain were collected on a litter basis, and the data are used as though the litter records for feed consumed were a characteristic of each pig in the litter. Feed data were adjusted to an equal starting and finishing weight for the pigs. It was suggested that in Minnesota No. 1 and Minnesota No. 2, selection was effective in slowing down the decline in numbers of pigs farrowed and weaned, especially when the two lines are compared (*33*). Further, that in the Minnesota No. 1 there was more selection for large initial litter size and there was a slower rate of decline in litter size, and in the No. 2 there was more selection for large litters at weaning and there seems to have been a less rapid rate of decline in the number of pigs weaned. It was suggested that in selection of sows for additional litters emphasis should be placed usually on the size of litter at weaning, disregarding size of litter at farrowing. Further, the replacement gilts should come from the litters largest at weaning time. Selection would, therefore, tend to be directed toward the optimum initial litter size from which the largest number of pigs could be weaned. The over-all results from the six lines have been interpreted as indicating in general that selection appears to have been an effective agent in the lines studied.

The report covering a study of pooled data relating to selection practiced in seven projects is extensive (*23*). Only an extremely brief summary of the points which seemingly are of most practical interest can be presented here.

Averages of selection differentials for litter size at farrowing and at weaning, litter weight and pig weight at weaning, pig weight at 154 days, and selection index, obtained from pooled data from six of the stations are shown in table 3. The averages show that selection was definitely positive for each of the characters indicated. Some variation between stations is evident but there is striking similarity in selection practiced for each character, except for the Illinois line selected for slow growth. Even in this case, selection for pigs farrowed and weaned is not greatly different from the other averages. The amount of selection for an index combining litter size and rate of growth also was calculated from the data of each station. Animals selected for breeding averaged slightly lower in degree of inbreeding than all pigs weaned at those stations. However, there was no deliberate attempt to select against inbreeding. In fact, the more highly inbred animals were likely to be favored unless their performance was inferior. Selection for lower inbreeding is shown in the last column of table 3.

Altogether, data on 4,669 litters from 40 inbred lines are included from the 6 stations. Approximately 30 boar and 27 gilt pigs were weaned per line in seasons when selections were made. Young boars sired 74 percent and gilts produced 60 percent of the pigs weaned, the remainder being produced by older boars and sows. Average age of parents, or interval between generations, was 1.27 years for sires and 1.41 years for dams. Only 8 percent of the boar and 33 percent of the gilt pigs weaned were kept to produce their first progeny when they were 1 year of age.

Calculations from these data indicate that if boars and gilts had been chosen at random, selection for size of the litters at weaning would have been nearly as great as that actually obtained. This result

is interpreted as meaning that most of the selection for size of litters was actually automatic, merely because more pigs from which to choose were available in the larger litters. Selection differentials for the lines in the Illinois project have a bearing on that point, since selection for increased size of litter occurred there even when choices were based only on weight of the pigs at 5 or 6 months of age.

Other calculations indicated that superiority of young sires and dams from deliberate selection was less than half what it would have been if all selection could have been based on the index,[24] combining litter size and growth rate. It was suggested that selection for something other than traits included in the index could be responsible for this, particularly in boars, where the discrepancy was greatest.

In the case of boars retained for use beyond 1 year, the data show that they were out of no larger litters than were all boars tested. This result was interpreted as indicating a shift of emphasis to individuality of the boar rather than to performance of the sow and litter from which these boars came. Thus, intensity of selection of sires for productivity and growth rate would have been improved if fewer older boars had been used. In general, opportunity for selecting sows on their own performance appears to have been exercised about as well as that for selecting gilts on the basis of their dam's performance.

Factors suggested which might have reduced deliberate selection among boar and gilt pigs are: (1) castration of too many boar pigs before their growth rate was expressed fully, (2) hernia, and undesirable conformation not reflected in the scores of the pigs, (3) losses from disease or injuries after weaning, (4) discrimination against pigs from the younger litters, and (5) reproductive failures.

There seemed to be a consistent tendency to select animals from the less highly inbred litters. This is indicated in the last column of table 3. Selection of the least inbred animals in these inbred populations is assumed to be the indirect result of selection for superior performance both of litters and individual pigs, presuming that such superior performances were associated with heterozygosity in the pigs selected. A major part of the variation in performance is due to environmental influences. Therefore, the genetic differences in overall performance must be associated rather closely with degree of inbreeding or the amount of heterozygosity, otherwise this unintentional selection of pigs with the smallest inbreeding coefficients would not have been so intense. Further, selection of the more heterozygous individuals would be expected to keep the frequency or ratio between the dominant and recessive genes more nearly intermediate. This may offer a partial explanation for the limited effectiveness of the selection practiced in the various lines. Effectiveness of selection would be limited either by genetic antagonism between characters (such as litter size and rate of growth) or by any tendency for environmental influences to cause a positive correlation between characters.

[24] The items included and the method of calculating the index are indicated in footnote 1 to table 3, page 26.

Genetic and environmental correlations between the characters involved in total performance also would affect both the size of the selection differentials and the extent to which they represent genetic superiority—that is, their effective heritability.

Selection for the characters considered in the studies made of the pooled data was definitely less effective than expected. Expected results were based on estimates of heritability of the characters, selection differentials, generation interval, and the declines which seem to be caused by the inbreeding. Actual time trends within lines, after removing the expected effect of the increased inbreeding, showed little or no change in litter size and a decline in growth rate, when the 10-year improvement expected from selection without inbreeding should have been about 10 percent in litter size weaned and 20 percent in weight at 154 days of age.

Effects of Inbreeding

Performance of the various inbred lines as inbreds has been reported in detail in publications listed at the end of this report. These indicate that there has been a decline in the number of pigs farrowed and weaned per litter. However, some lines have held up rather well, particularly as to the number of pigs farrowed and growth rate.

The decline in number of pigs farrowed is estimated from all data to be about one-third of a pig per litter and for number weaned about one-half pig per litter for each increase of 10 percent in inbreeding. Strength and liveliness of pigs at birth appeared to be reduced, in some lines at least, as inbreeding increased. Rate of growth declined in some lines but apparently not in all. Economy of gain seems to have been improved a little in some lines under inbreeding and selection. It appears that inbreeding doesn't affect economy of gain as much as it does some other performance characters. Seemingly the rate of physiologic maturity declined in some lines. This is suggested because the age at which inbred gilts came in heat, and the age at which inbred boars began service seemed to be lagging a little as inbreeding progressed in some lines (*1, 40, 39, 71*). Some of the studies made in respect to physiologic differences between boars have shown that lines differed in one or more respects (*1, 18, 34, 35, 36, 37, 90*). These involve rate of testes growth and development, substances secreted, sexual behavior, and variations in age when boars began service. Studies made of testes of inbred boars suggest that development of the testes and production of sperm were delayed by inbreeding (*1, 40, 77*). Observations made of inbred gilts indicated that the number of eggs shed was less than in noninbred gilts. The number of eggs shed at a heat period seems to have been reduced in some lines by inbreeding (*71*). Observations relating to age at puberty or the first heat period in gilts indicate differences between lines (*80*).

Litter size is seemingly much more difficult to maintain in lines being inbred than is growth rate (*16, 29*). Analysis of data in regard to death losses in one of the projects showed that the percentage of stillborn pigs increased 1.6 percentage points with an increase of 10

percentage points in the inbreeding of the dam. Inbreeding of the dam had small or doubtful effects on mortality of pigs after birth. Total mortality, including stillborn, increased 4.2 percentage points with each increase of 10 percentage points in inbreeding of the litter (*78*).

Other studies have indicated that neither inbreeding of the sow nor inbreeding of the litter had a significant effect on survival of pigs from birth to weaning or on total weaning weight of the litter (*33, 95*). The selection practiced appeared to have been effective in preventing declines commonly reported as associated with inbreeding.

The length of gestation periods for sows seems to have been increased a little by inbreeding. Records on 1,682 sows for 2,517 gestations in one project (*63*) and 956 gestations in another (*2*) show that differences between lines in regard to length of gestation period accounted for more of the variation than other factors studied. Weight of litters was next in importance in that regard.

Differences in performance between lines usually have become evident by the time inbreeding increased to about 25 to 35 percent.

Averages by years for number of pigs farrowed and weaned per litter and for inbreeding of the litters are shown in figure 2 for the

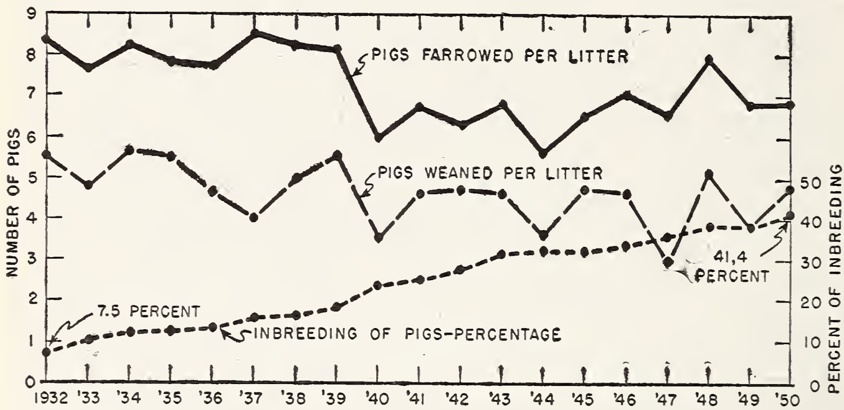

FIGURE 2.—Average number of pigs farrowed and weaned per litter by years, and the average inbreeding of the pigs by years for the Poland China 4-sire line at the Iowa station. (Adjusted to a gilt basis.) (From Kottman (*50*).)

4-sire line in the Iowa project. These averages are of particular interest because they cover a period of 18 years with moderate inbreeding. In figures 3 and 4 results are shown for the 2-sire and 1-sire lines, respectively, but for a shorter period than the 4-sire line. Averages for weaning weight and weight at 154 days by years for the lines grouped according to the number of sires used, are shown in figure 5. The charts show a large amount of variation in the different performance traits from year to year in these lines and breeding groups, and that improvement occurred after 1947. The recent improvement indicated is regarded as a reflection of improvements in environmental factors.

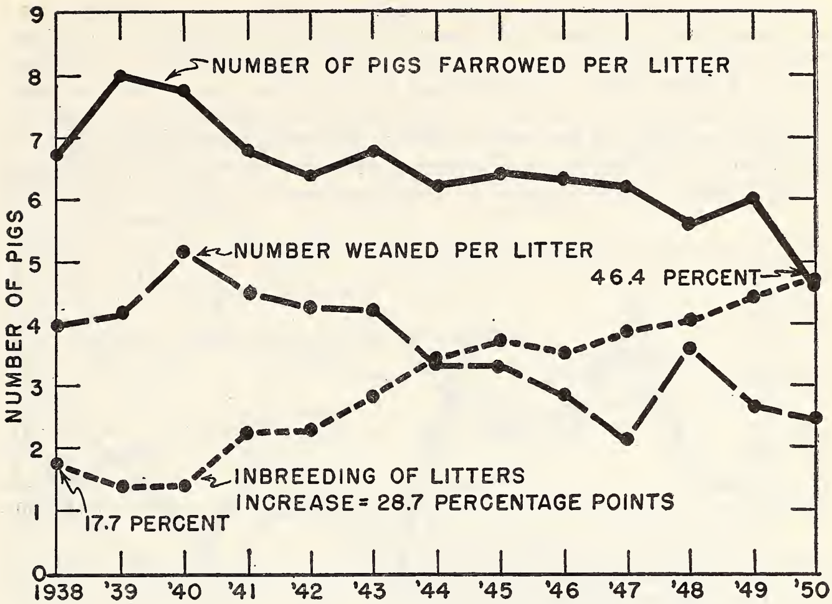

FIGURE 3.—Average number of pigs farrowed and weaned per litter by years, and the average inbreeding of the pigs by years for the Poland China 2-sire lines at the Iowa station. (Adjusted to a gilt basis.) (From Kottman (*50*).)

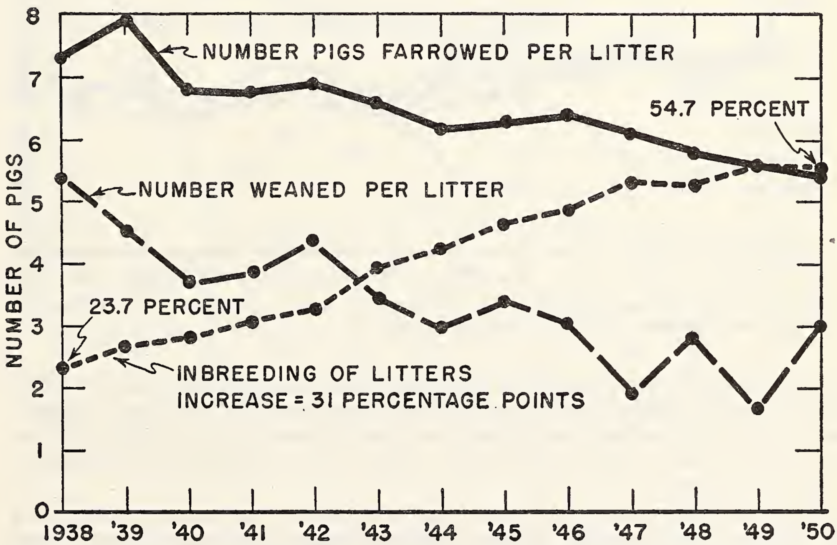

FIGURE 4.—Average number of pigs farrowed and weaned per litter by years and the average inbreeding of the pigs by years for the Poland China 1-sire lines at the Iowa station. (Adjusted to a gilt basis.) (From Kottman (*50*).)

In figure 6 averages for farrowing, weaning, and inbreeding per litter are shown by years for a line of Durocs in the Oklahoma project. Attention is called to the seemingly large improvement in numbers farrowed after 1946. It is believed that at least part of the increase shown is due to environmental improvements made at that time, including pasture and the ration fed to the sows during gestation.

Results for farrowing and weaning with an inbred line of Chester White (White King) in the Indiana project are shown in figure 7.

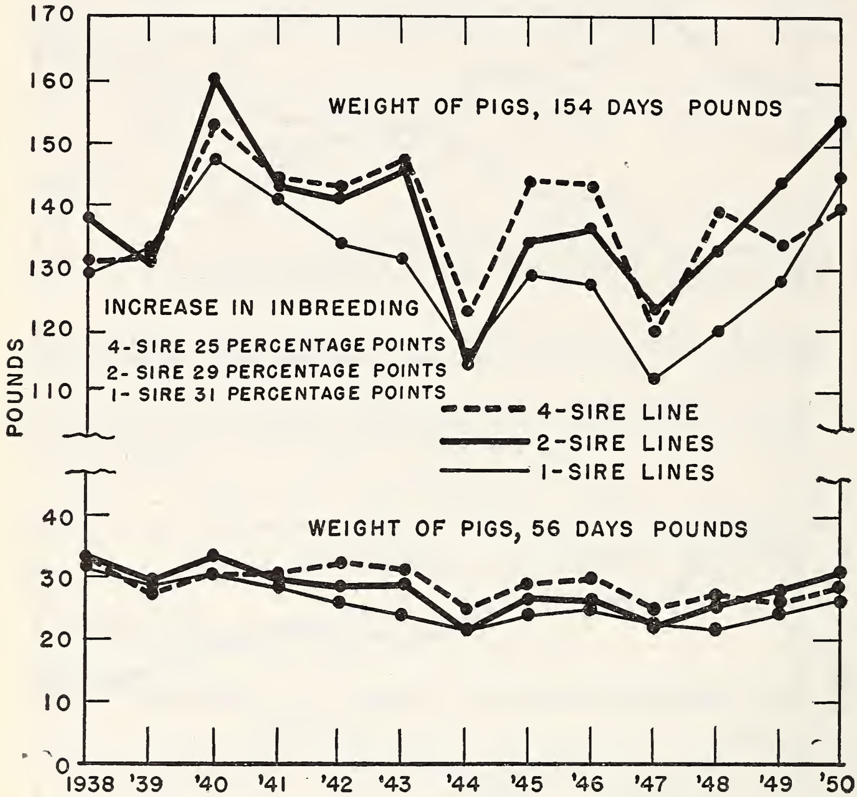

FIGURE 5.—Weight per pig at 56 and 154 days by years for Poland China lines at the Iowa station. (From Kottman (*50*).)

This is one of the lines that had shown only a small decline in farrowing until 1950 when it dropped to 6.3 pigs per litter. But numbers farrowed bounced back to 8.3 and number weaned to 6.2 in 1951. This is another case which apparently reflects the influence of environmental factors.

Data on farrowing and weaning are shown in figure 8 for the Minnesota No. 1 at the North Central branch station. This is one of the lines in which numbers farrowed have held up well under inbreeding, and numbers weaned held up well except for about 3 years. Data in the chart emphasize particularly the influence of environmental factors on numbers of pigs weaned.

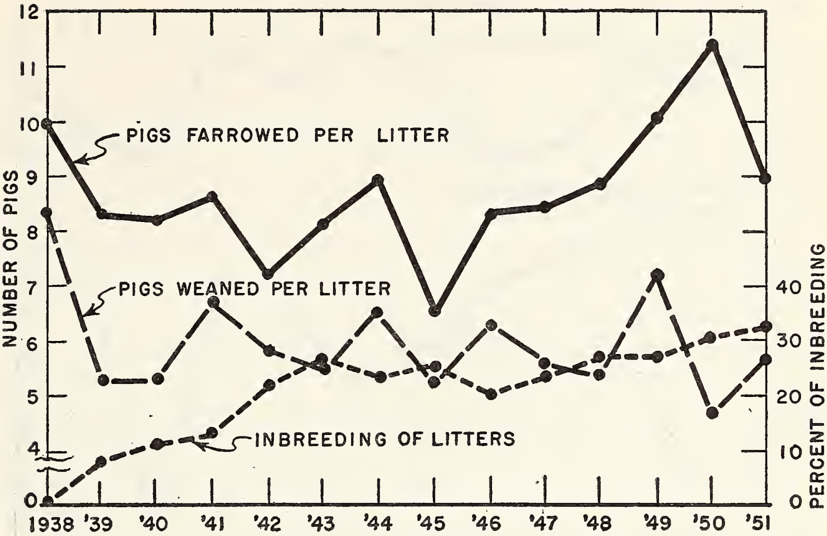

FIGURE 6.—Average number of pigs farrowed and weaned per litter by years, and the average inbreeding of the pigs by years for Duroc line 3 at the Oklahoma station. (Adjusted to a gilt basis.) (Data supplied by Whatley.)

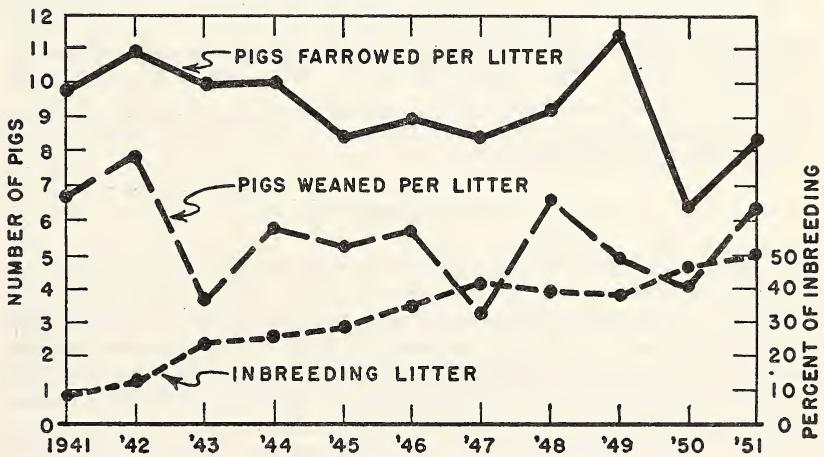

FIGURE 7.—Average number of pigs farrowed and weaned per litter by years, and the average inbreeding of the pigs by years for the Chester White-White King line at the Indiana Station. (Adjusted to a gilt basis.) (Data supplied by Wiley.)

Although inbreeding tends to depress full expression of performance characters, the over-all results indicate that when selection is practiced to the fullest extent possible, some lines may perform reasonably well, at least for several generations of inbreeding at a moderate rate.

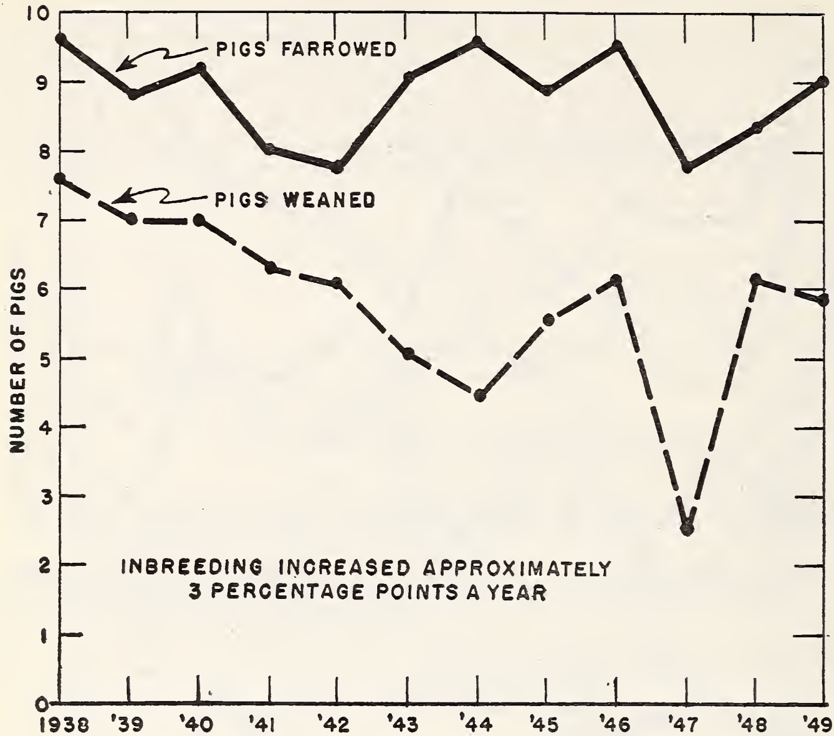

FIGURE 8.—Average number of pigs farrowed and weaned per litter, Minnesota No. 1 gilts only, North Central Branch Station, Grand Rapids, Minn. (Data from Fine and Winters (*33*).)

LINECROSSING

The principal value of inbred lines is largely due to whatever advantages are obtained from their use in crosses. Performance of lines themselves, although of utmost importance in a practical sense, does not appear to be a complete measure of their crossing value. Tests seem to be essential for finding the "nicking" value of lines with each other, and for use with noninbred stock. Trials for testing inbred lines in various types of crosses have been conducted by each of the stations. Only a brief summary can be given here, and not all of the different types of crosses are included. A few of the published reports are cited specifically. Generally the lines used in crossing trials were those doing best as lines, but some lines used were definitely not among the best in one or more respects. The characters most adversely affected by inbreeding appear generally to show the most favorable response to crossing. Crosses of two lines in which numbers of pigs farrowed and weaned had declined under inbreeding, have shown increases ranging usually from near zero to 20 percent in numbers farrowed, and from 6 to more than 40 percent in numbers weaned, as compared with litters of the parent lines. Growth rate of the pigs

from 2-line crosses, litters out of inbred sows of one line and sired by an inbred boar of a different line of the same breed, has exceeded inbred pigs of the parent lines generally by 10 to 30 percent. These comparisons of litters from 2-line crosses with litters of the parent lines indicate the effect of hybrid vigor in the pigs from crossing two inbred lines when the dams of both groups are of the same line (*14*).

Three-line crosses, litters out of 2-line cross sows and sired by a boar of a third line of the same breed, have been compared with 2-line crosses of the same breed. In most of these trials 3-line cross litters have definitely exceeded the 2-line crosses in numbers of pigs farrowed and weaned. Sows selected from 2-line crosses are not inbred and they generally show advantages in number of pigs farrowed and weaned when compared with sows produced from noninbred stock of the same breed. The differences between litters from 2-line and 3-line crosses range from only a little to more than 20 percent, the average being approximately 12 to 15 percent. These comparisons indicate the effect of hybrid vigor of the dams in case of the 3-line crosses combined with that of the pigs. It is clear that the pig-farrowing and pig-raising ability of cross line sows is superior to that of the sows in the parent lines.

Growth rate of the individual pigs from 3-line crosses generally has exceeded that of 2-line crosses up to weaning, which largely reflects hybrid-vigor effects in the dams. When pigs of these two types of crosses are put on their own after weaning there seems to be little difference as to the amount of hybrid vigor between them, and individual weights at 5 to 6 months of age are closely similar.

Results from line crosses show that when the lines were related, that is from the same foundation, differences between the line crosses and the parent lines usually were small. An example of the latter is found in a study of lines at the Nebraska station (10). Several reports relating to trials of crossing lines within breeds have been published (*14*, *16*, *29*, *70*, *85*, *96*, *98*).

Linecrosses have been compared also with noninbred purebred controls of the same breed. These trials have shown generally some advantage in favor of 2-line and 3-line crosses for individual weight per pig at 5 to 6 months of age. But only the 3-line crosses usually have shown advantages over the controls in numbers of pigs. Although improvement in the lines themselves during the period of inbreeding generally seemed negative, advantages obtained in case of the 3-line crosses are believed to indicate that the selection within and between lines for performance characters was effective in improving the performance of lines in crosses (*29*, *85*).

An example of results obtained from cross lines within the same breed is shown in figure 9. Two-line and three-line crosses were compared with noninbred Durocs. It is evident from the chart that litters of 2-line crosses, both sows and boars being inbred, averaged fewer pigs at farrowing and weaning than the noninbred Duroc controls. The 3-line crosses were litters from sows which were 2-line crosses except that a few were 3-line crosses, and were by boars from a third inbred line. These 3-line crosses averaged slightly more pigs than the controls. Crossbred litters by inbred boars of other breeds and out of noninbred Duroc sows excelled each of the other groups in numbers

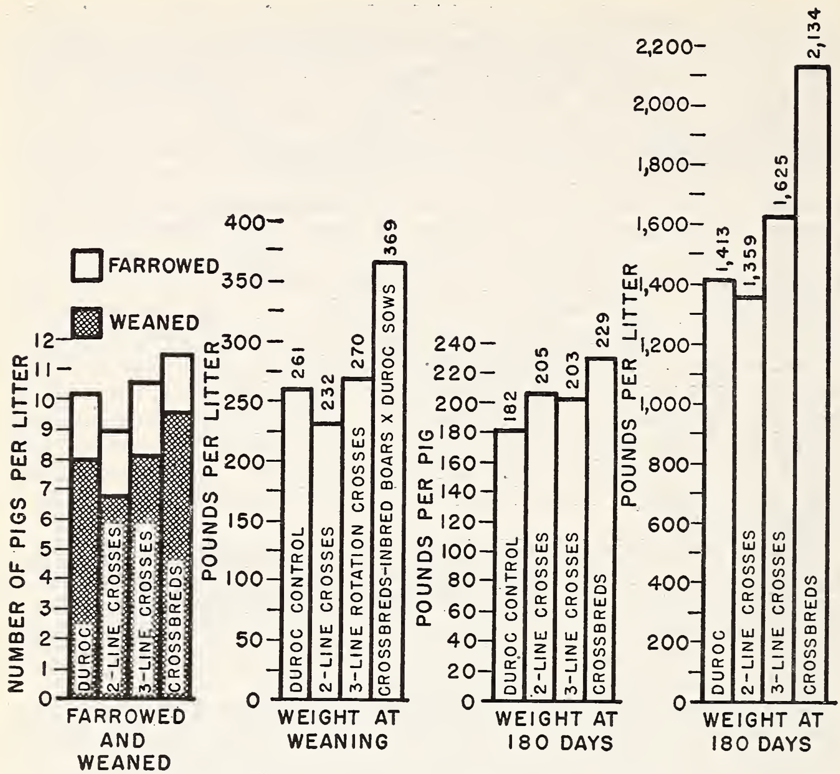

FIGURE 9.—Comparison of purebred Duroc 2-line crosses, and 3-line crosses, with noninbred Duroc, and crossbreds by inbred boars of different breeds on Duroc sows. (Data supplied by W. L. Robison of the Ohio Agr. Expt. Sta. Trials were conducted 1942–50 and include 199 litters; crossbreds were produced only in 1950.)

farrowed and weaned. Hybrid vigor in each of the crossed groups is indicated by weight at weaning, and at 180 days of age. On the basis of individual pig weights, 2- and 3-line crosses are about the same. That appears to be the usual result. But on a litter basis 3-line crosses generally have been definitely superior to the 2-line crosses, because of having more pigs per litter. Three line cross litters usually have exceeded noninbred controls from about 7 to 15 percent in weight at 5 to 6 months. About 15 percent was the case in the Ohio trials. In the Ohio tests in 1950, Duroc sows produced litters by inbred boars of other breeds. The results for these litters also are shown in figure 9. Robison cautions, however, against direct comparison of these with the other groups because these were produced only in 1950 and some of the difference in their favor could have been due to improved feeding and management.

Crosses of lines from different breeds generally have shown considerably more hybrid vigor than that indicated in the line crosses within a breed (*31*, *70*, *81*, *96*, *98*). These results suggest strongly that for

the best results in crosses, it is important to have as much genetic difference as possible between lines. This point is brought out particularly in crossing trials in the Minnesota project (*70*, *96*).

A few trials have been conducted in which crosses from inbred lines of different breeds were compared with purebred noninbred controls and with crossbreds from conventionally bred purebreds. There appears to be some advantage in favor of line crossbreds as compared with the conventionally bred crossbreds (*81*).

Topcrossing

Inbred boars of several different lines and noninbred boars have been used in topcrosses on similar groups of sows through cooperation of farmers. In these tests litters by an inbred boar could be compared directly in the same season and on the same farm with litters by a noninbred boar. One of these studies has been reported in detail (*31*). Thirty-eight boars representing several inbred lines were used in trials which included 680 litters produced on 44 farms in Wisconsin. Litters by inbred boars from 4 of the lines definitely excelled those by the noninbred boars in rate of gain and 154-day weight, which is regarded as indicating that the inbred lines differed in their ability to combine with outbred stock. Then performance of 200 gilts from litters by the inbred boars and of 238 gilts by the noninbred boars was compared on the farms where they were raised. Results from the topcross and nontopcross gilts are shown grouped according to line of sire in table 4. An over-all difference was found in favor of the gilts by the inbred boars, which amounted to a little more than one pig per litter at farrowing and weaning, and about 37 pounds in weight of litters weaned.

Trials are in progress at some stations in which inbred boars of different lines are used in rotation to produce "rotation line crosses." Results being obtained in a line-crossing trial in progress at the South Dakota station are shown in table 5, which illustrates some of these tests. Four different breeding groups are included in this project. The differences between the groups are not large but on the whole an advantage is evident in favor of the four breed rotation line crosses followed by the four-line rotation within the same breed. To get the maximum in results from "rotation line crossing" may require much testing for the best combination of lines with respect to the different performance characters.

Combining ability or "nicking" of lines, which is important in corn, appears to be important also in swine. Conclusions from one extensive study of records on line crosses within the same breed at one station emphasize that point (*46*). Therefore, finding the best combination of lines probably will require much testing.

An example is presented, in tables 6 and 7, of trials for comparing different line crosses using only four pigs per litter, fed from weaning to market weight in dry lot. Feed lot performance of each group is considered good. There are evident differences between the groups, however. These records were obtained in search of the best combination of lines for growth rate, economy of gains, and carcass quality.

TABLE 4.—*Number farrowed, number weaned, and weaning weights of the litters of 200 topcross and 238 nontopcross gilts grouped by line of inbred boar used for each topcross group*

Line	Number farrowed			Number weaned			Weaning weight of litter		
	TC [1]	NTC [2]	TC–NTC [3]	TC	NTC	TC–NTC	TC	NTC	TC–NTC
LPC [4]	10. 47	8. 24	[5] 2. 23	8. 30	6. 55	[6] 1. 75	252. 7	186. 7	66. 0
LCW [7]	9. 73	9. 15	. 58	7. 32	6. 79	. 53	196. 0	166. 4	29. 6
Land. [8]	12. 50	9. 50	[5] 3. 00	10. 50	8. 10	[5] 2. 40	261. 1	232. 5	28. 6
PC [9]	8. 60	8. 28	. 32	6. 13	6. 22	—. 09	165. 8	146. 3	19. 5
AK [10]	10. 30	9. 30	1. 00	8. 70	7. 65	1. 05	237. 8	202. 6	35. 2
PM [11]	9. 90	10. 07	—0. 17	7. 40	6. 30	1. 10	192. 4	130. 9	61. 5
MA [12]	9. 30	8. 87	. 43	7. 23	6. 78	. 45	180. 4	168. 0	12. 4
CY [13]	8. 00	6. 07	[5] 1. 93	5. 50	4. 10	1. 40	139. 9	98. 7	41. 2
Over-all average	9. 85	8. 69	[6] 1. 16	7. 64	6. 56	[6] 1. 08	203. 6	166. 4	[6] 37. 2

[1] TC=topcross.
[2] NTC=nontopcross.
[3] TC-NTC=difference between the two groups.
[4] LPC—Landrace-Poland China (76 percent Landrace, 24 percent Poland China)—Beltsville.
[5] $P \leq .05$.
[6] $P \leq .01$.
[7] LCW—Landrace-Chester White (80 percent CW, 20 percent Landrace)—Beltsville.
[8] Land—Landrace—Iowa.
[9] PC—Poland China (several lines pooled—Scoutmaster, Alliance, Blackbird, and inbred linecrosses of these and other lines)—Iowa.
[10] AK—Alfalfa King (Chester White)—Wisconsin.
[11] PM—Purdue's Moderator (Chester White)—Wisconsin.
[12] MA—Model A (Chester White)—Wisconsin.
[13] CY—Chester Yorkshire (50 percent Chester White, 50 percent Yorkshire)—Wisconsin.

Data from Wisconsin Station trials on 44 Wisconsin farms, inbred and noninbred boars used on same farm in same season (*31*).

TABLE 5.—*Summary of results comparing linecrosses within the Poland China breed and breed-linecrosses (Poland China, Hampshire, Duroc, Landrace) with outbred Poland China control, 1947 to 1951*

Item	Poland China 4-line rotation cross	4-breed-line rotation cross	Poland China outbred control	Poland China line topcrosses [1]
Number of litters	33	39	33	14
Average number of pigs per litter:				
Farrowed	7.5	9.0	6.3	7.6
Weaned [2]	5.5	6.9	4.3	5.2
Average weight per pig:				
Farrowed	2.6	2.9	2.7	2.8
Weaned	28.8	32.2	29.6	25.8
154 days	143.4	157.8	145.8	143.3
Feed per cwt. of gain [3]	367.4	353.7	372.8	[4] 310.5

[1] Boars were from crosses of 2 inbred Poland China lines, sows were noninbred Poland China; these litters were produced only in 1950, 1951.
[2] Based on litters weaned.
[3] For years 1947 through 1950.
[4] For only 7 litters raised in 1950.

Data from South Dakota Experiment Station supplied by McCarty and Wilder.

TABLE 6.—*Results from record of performance tests with linecrosses of inbred Poland China and inbred Landrace at the Iowa Station*

(4 pigs tested per litter—1949, 1950, 1951)

Linecrosses	Number of litters	Weight per pig at 154 days	Feed required per 100 pounds of gain
		Pounds	*Pounds*
Poland China × Poland China	56	202	355
Poland China × Landrace	26	231	339
Landrace × Poland China	26	222	324
Landrace × Landrace	6	232	349

Data supplied by Hazel and Lush.

TABLE 7.—*Results from record of performance tests with inbred Duroc and inbred Chester White boars mated to crossline Poland China and Poland China-Landrace sows at the Iowa Station, 1950–51*

Breeding of boars	Breeding of sows					
	Crossline Poland China			Poland China-Landrace		
	Number of litters	154-day wt.	Feed required per 100 pounds of gain	Number of litters	154-day wt.	Feed required per 100 pounds of gain
		Pounds	*Pounds*		*Pounds*	*Pounds*
Inbred Duroc	4	202	331	20	217	333
Inbred Chester White	6	185	338	23	206	335

Data supplied by Hazel and Lush.

Physiologic Problems in Breeding

Factors of a physiologic nature may cause irregular breeding of sows, low fertility, complete sterility, and death of embryos during gestation. Some of these factors have been investigated in projects where circumstances were suitable for such studies. Observations which seem to have a direct bearing on the problems met in the inbred lines included repeat breeding or failure of sows to settle, impaired fertility resulting from structural and physiologic defects, effects of age at breeding, effects of protein level fed and rate of feeding on the number of eggs shed, and failure of fertilized eggs to develop. Physiologic studies with boars were mentioned under effects of inbreeding (p. 29).

A sample of 79 sows and gilts with unsatisfactory breeding history was studied in the Illinois project (*91*). These sows came from farms in Illinois and from the station herd. When bred at the station slightly more than half of these settled and had normal embryos when slaughtered about 39 days later. Abnormal conditions of one sort or another were found in the reproductive tract of about 7 percent of the pregnant sows. Very little evidence of complete embryonic mortality of individual litters was observed in this sample of sows, but observations of ovaries and the uterus indicated that about 26 percent of the eggs did not develop into pigs. Examination of the sows that did not settle revealed several types of abnormalities in 37 cases, but in 4 cases no reason for sterility was found.

Several studies at the Wisconsin station involving physiologic problems in rather large numbers of animals have been reported. Observations in respect to abnormalities of the reproductive tract were made on 5,088 females at time of slaughter in a packing plant. Approximately 5 percent both of open sows and of gilts had abnormalities of one sort or another which are known to impair fertility. In addition to these about 9 percent showed abnormalities which did not appear to have a marked effect on fertility (*88*). Sixty-three sows with a history of reproductive failure were obtained from farms, and studied (*79*). These had failed to produce litters after being bred during two to four successive heat periods. Failure of fertilization in about one-half of the gilts and one-third of the sows appeared to be the cause of repeat breeding. Structural abnormalities or failure to shed the eggs from the ovaries accounted for failure of fertilization in 50 percent of the gilts and 16 percent of the sows. Death of embryos accounted for one-fourth of the repeat breeding in gilts and two-thirds of it in the sows. In another study with noninbred gilts, 38 percent of the eggs shed were lost by the 25th day, presumably from embryonic death. Gilts on limited feed tended to have more embryos at 25 days than gilts which were full fed. When they were on pasture, gilts on a high protein ration tended to produce more eggs than gilts on a low protein ration, but when they were in dry lot the gilts on a low protein ration produced more eggs than those on high protein. The faster-growing gilts appeared to reach puberty earlier than the slower-growing gilts (*66*).

The number of eggs shed at first and second heat was studied in 48 gilts. These averaged nearly one more egg shed in the second heat period than in the first. Those conceiving at the third heat period

farrowed 1.4 more pigs than gilts which conceived at the second heat and 2.5 pigs more than those conceiving at the first heat (*80*). Another sample of gilts shed two more eggs at second heat than at the first heat (*66*). A definite breed difference was found between noninbred Chester White and Poland China gilts as to number of eggs shed at first and second heat periods. The percentage of eggs fertilized and the survival of embryos showed definite breed differences also (*67*). An investigation based on 2,967 gilts in a packing plant indicated that season of birth affects rate of sexual development. In addition 113 gilts of known ages were studied in that regard. Gilts born in the spring were slower to reach sexual maturity than those born in other seasons (*89*).

The number of eggs shed was studied in 277 gilts and 72 sows in the different breeding groups at the Missouri station (*71*, *72*). Sows shed about 4 more eggs than the gilts. The average number of eggs shed by gilts of the different groups of breeding ranged from 9.7 for Poland China inbred line II to 13.5 for a crossbred group.

Samples of the females from the breeding groups were slaughtered 25 days after breeding for observation of the embryos. The number of fertilized eggs found averaged definitely greater for the crossbreds than for the parent lines in the case of both sows and gilts. Total mortality of eggs at 25 days was 35 percent for both gilts and sows. Number of eggs shed and embryonic mortality in the gilts were both related to age of the gilts at breeding. Together the two accounted for an increase of one half pig for an increase of 10 days in age at breeding for the young gilts. Other studies have shown that the size of litters farrowed increased with the size of gilts or age of gilts when bred (*74*).

These results emphasize the importance of physiologic maturity of gilts at time of breeding. The reports indicate clearly that abnormalities in the reproductive tract are responsible for some of the reproductive failures in noninbred as well as for inbred sows and gilts. Evidently more than one-fifth of the eggs shed from the ovary do not develop into pigs. Such losses have been reported by different investigators for many years. At present the causes of embryonic losses seem to be largely beyond the breeder's control.

Carcass Studies

In a broad sense hogs are used in the United States to convert corn to pork and lard. Between 40 and 50 percent of the corn crop is fed to hogs. In turn hogs provide nearly half of the meat supply of the country. In general, the 5 principal trimmed cuts—hams, loins, picnic shoulders, Boston butts, and bellies—from 220-pound hog total about 100 pounds. Although there is continuous variation as to prices for the different cuts and for lard, these 5 wholesale cuts account roughly for three-fourths of the value of the carcass. The remainder—spare ribs, feet, jowls, plates, etc.)—brings the total edible part to approximately 130 pounds. In addition about 30 pounds of lard is obtained. Per capita annual consumption of pork averages near 70 pounds; of lard, 13.

The supply of vegetable fats and oils has been increasing for many years. These compete directly with lard. For a long time now, the

wholesale price of lard has been much less per pound than the market price of live hogs. There is evidence also of increasing consumer preference for lean meat. Pork cuts must be trimmed relatively free from outside fat and they must not show evidence of excessive fatness in the lean portion or the housewife discriminates against them. Increasing competition of vegetable fats and oils with lard, and increasing consumer preference for lean meat are matters the hog producer must face. This situation is not new but apparently it is becoming progressively more serious. It seems important, therefore, that breeders follow breeding, selection, and feeding methods that reduce the yield of fat and in turn increase the yield of lean meat of acceptable quality.

Project leaders have been mindful of these circumstances, and have given attention to these problems in each of the projects in the laboratory. Studies undertaken, however, have differed between stations for numerous reasons. Attention has been focused on determining the character of carcasses of various inbred lines and linecrosses, the relationship between production characters and composition of carcasses, and methods which might be used in evaluating carcass desirability in live hogs.

Records obtained on carcasses of the various lines and linecrosses have shown definite differences between the breeds and also between lines within the same breed. Carcasses from linecrosses out of lines differing appreciably in carcass characteristics usually have been intermediate between the parent lines with respect to individual traits. Usually the combination of characters expressed in crosses produced carcasses which were superior in desirability to those from either of the parent lines. Carcasses have been rated on the basis of yield of the 5 primal cuts, together with thickness of backfat, length of carcass, and an estimate for quality of the cuts. Scoring schemes have been tried also in evaluating carcasses before cutting. No means has been found for combining the various items into an overall rating of carcasses which is satisfactory generally in research studies. Yield of the 5 primal cuts appears to be the most satisfactory single measure. However, yield of these cuts alone does not evaluate quality of the cuts, and quality is important. Fat in excess of the amount needed for a reasonable degree of firmness lowers the quality and desirability of pork.

The carcasses which have rated highest are from 210- to 230-pound hogs and average about 30 to 31 inches long with the thickness of backfat averaging about 1.5 to 1.7 inches. These carcasses have yielded from about 46 to more than 50 percent of the live weight of the hog in the 5 primal cuts, and from about 68 to more than 70 percent of the cold carcass weight is in these 5 cuts. Generally the cuts from these carcasses have not shown excessive fatness and they have been rated reasonably firm, and otherwise of high quality. Many inbred lines and linecrosses have produced a high percentage of carcasses with these characteristics.

Differences between breeds and also between lines in the same breed suggest that breeding or heredity plays an important part in causing the variations. In two projects estimates of heritability have been calculated for variations in some of the carcass characters. Variations in thickness of back fat, length of hind leg, and circumference

of ham in the Nebraska data indicate heritabilites of about 12, 23, and 17 percent respectively (*7*). Calculations from Iowa data indicate heritabilities of 29 percent for lean cuts, 52 percent for fat cuts, 73 percent for length of carcass, 58 percent for length of hind leg, and 54 percent for thickness of back fat (*22*). These results suggest that highly variable estimates are likely from similar studies of other data. But they definitely indicate that part of the variation is heritable.

Carcass differences between lines and breeds in the Minnesota project have been reported (*19*). Real differences were found between the various groups, in yield of the 5 primal cuts, fat cuts and, also in measurements taken on carcasses. Comparisons included samples of noninbred Durocs, Poland Chinas, and Chester Whites from the University herd, samples selected from the regular market run, one group of topcrosses by a Minnesota No. 1 boar from a farm herd, and swine produced at the Minnesota branch stations from inbred lines and from various crosses between the lines. Altogether there were 741 carcasses from 50 groups differing in breeding.

The best carcasses, when yields and quality of the cuts were considered together, came from the crossbred groups, and from one group of Poland China linecrosses. Carcasses from crosses were superior to the parental lines because of the combination of desirable carcass characters they possessed. In most cases the crosses were intermediate between the parental lines for individual carcass traits. When the Minnesota No. 1 was used in a cross, the length of carcass, yield and quality of bacon increased over those of the other parent line. In crosses where Minnesota No. 2 was used the yield of loin and thickness of lean in the belly increased, and the amount of excess fat was reduced. When one of the Poland China lines was used, yield of ham was increased. The most outstanding carcasses came from hogs of the following three crosses: Minnesota No. 1, Minnesota No. 2, and V-line Poland China; Minnesota No. 1 and Minnesota No. 2; and the C-line Poland China and Minnesota No. 1.

The fattest carcasses were from the noninbred groups of Chester Whites and Durocs. These groups were among the lowest in yield of the 5 primal cuts. Carcasses from the noninbred Poland China group were fairly good in yield of the primal cuts but were fatter than most of the inbred lines of Poland Chinas. Some of the poorest carcasses came from a few of the Poland China lines which have been discontinued.

Carcass differences between lines and crosses in the Oklahoma project have been investigated (*87*). Comparisons included 5 inbred Duroc lines, 2-line crosses, 3-line crosses, noninbred Durocs, Landrace-Poland China from Beltsville, and crossbred groups from Minnesota No. 2 and noninbred Poland China boars on Duroc linecross sows. Differences between the Duroc lines were small, except that one line was definitely inferior to the average of the other 4 lines in percentage of ham and lean area of ham.

Differences between the various Duroc line crosses were evident but on the whole these were small. Likewise differences between carcasses from the noninbred Durocs, the inbred Durocs, and the Duroc line crosses were small. Carcasses from crosses of noninbred Poland China with Duroc linecross sows and from Minnesota No. 2 with Duroc line cross sows were definitely superior to the Duroc groups.

The carcasses from the Landrace-Poland China line, though a little soft, were longer, leaner, and higher in percentage of lean cuts than those from the other breeding groups. In the opinion of the observers the most desirable carcasses were in the two crossbred groups.

The effect of different levels of feeding on carcass characteristics in the Minnesota project has been reported (*19*, *99*). Four lots of 20 pigs each were started at an average weight of about 42 pounds and fed to a final weight of approximately 215 pounds. Lot 1 was self-fed for the entire period; lot 2 was self-fed to 125 pounds, then feed was restricted to 3 percent of the body weight; feed for lot 3 was restricted to 3 percent of the live weight until the pigs weighed 125 pounds, then self-fed to the finish; feed for lot 4 was restricted to 3 percent of the live weight for the entire period. Pigs used were purebred Durocs, Chester Whites, and Poland Chinas from the University herd. Average daily gains for the pigs over the entire period were 1.4, 1.19, 1.11, and 0.92 pounds, and feed required per 100 pounds of gain was 383, 381, 391, and 365 pounds for the four lots respectively.

Composition of the carcasses was altered by thus subjecting hogs of similar breeding to different levels of feeding. In comparison with the self-fed lot, yield of primal cuts was increased and yield of fat cuts was reduced by restricting the feed to 3 percent of the live weight for the entire feeding period. Likewise self-feeding to 125 pounds, followed by restricted feeding to slaughter weight, increased the yield of primal cuts and decreased the yield of fat cuts, but less than when feed was restricted throughout the feeding period. There was no difference in yield of primal cuts between the carcasses from the lot self-fed all the way and those from the lot restricted in feed to 125 pounds followed by self-feeding to the finish. But carcasses of the latter lot yielded less proportional weight in fat cuts than those from the lot self-fed for the entire period.

The relation between rate of growth and characteristics of carcasses has been reported from three projects. Results from these studies are of particular interest because they differ somewhat as to conclusions. In one of these studies the records on 578 Poland Chinas, 114 Landrace, and 54 Landrace-Poland China crossbreds in the Iowa project were used (*22*). An association between rapid rate of gain, rapid fat deposition, low feed requirements, and poor suckling ability of sows was indicated. These results were interpreted as suggesting strongly that the four traits tend to be affected by the same genes.

This suggestion from the swine data was tested in an experiment with mice (*24*). Feed required per unit of gain in weight was little more than half as much for the rapid fattening "yellow" mice as for "nonyellow" litter mates, which increased in weight much more slowly than the "yellow." It was concluded that the extremely rapid rate of fattening that is characteristic of the "yellow mouse" resulted from its inherited lower food requirements for maintenance and activity and its higher food consumption than for the "nonyellow" litter mates. On the basis of these results it was suggested that a breeding program for increasing rate and economy of gains in swine should be based on (1) selection for growth rate on the basis of weight of pigs at about 4 months of age, before heritable differences in fatness are expressed fully and while a large part of the variation in weight of pigs is due to differences in suckling ability of the dams, (2) selection for suckling

ability on the basis of number and weight of pigs at some time during the suckling period, and (3) final selection from litters surpassing line or herd averages for rate and economy of gain after weaning.

Results relating to rate of gain and carcass characteristics for 416 Duroc hogs of inbred lines were reported from the Nebraska project (*7*). Relationships between gains, depth of back fat, and circumference of ham were positive but low. The association between length of hind leg and rate of gain was negative, but low. The degree of hereditary association indicated between rapid gains and fatness was less than that reported in the Iowa data. Differences in the breeds used at these stations might be a factor in that respect.

Investigations of the relationship between growth rate and carcass characteristics in the Minnesota project are based on the records of 465 hogs from the inbred lines and the University herd (*19*). Rate of growth was measured in several different ways. Breed differences were important, but in nearly all cases there was no association between growth rate and yield of primal cuts or the yield of fat cuts. The exceptions were that pigs of the same slaughter weight and of the same breeding, with a high weaning weight and a high growth rate from weaning to slaughter yielded carcasses with a high percentage of primal cuts. Accordingly pigs that reached 200 pounds at an early age also produced carcasses with a high percentage of primal cuts.

It was found in the study relating to plane of nutrition, economy of gain, and carcass quality in the Minnesota project, that when adjustments were made for maintenance requirements, pigs fed a restricted ration throughout the trial required less feed and less nutrients per unit of gain than pigs full-fed. Pigs fed at the restricted level produced the leanest carcasses. Accordingly it was concluded that less nutrients are required to produce a unit of lean meat than a unit of fat; therefore, selection of breeding stock on the basis of economy of gains should be somewhat effective as a means of producing hogs that yield a lean carcass. On a basis of the over-all results it was suggested that the task of the animal breeder is to search for desirable combinations of genes, and when desirable combinations in existence are not found his task is to break the old combinations, create new combinations, and from these sort out the most desirable ones for developing superior lines or breeds.

Studies have been conducted by investigators in different countries for many years in respect to the relationships between measurements taken on various parts of hog carcasses and the yields. Such information has been sought for the purpose of predicting yields, quality, and total value of carcasses. If yields of cuts could be predicted accurately, cutting would not be necessary, and the problem of evaluating hog carcasses would be facilitated. There is general agreement about the relationships, but their predictive value is low.

In each of the projects, samples of carcasses from the various breeding groups have been measured to obtain records for evaluating the differences between groups. These records have been useful in characterizing lines, but they have not been entirely satisfactory for predicting yields and quality of cuts.

Generally the thickness of back fat indicates the total fat content of a carcass more accurately than other items that have been measured. But more accurate measures are being sought for predicting carcass

values. Weight per inch of length, divided by average thickness of back fat, has shown higher predictive value than thickness of back fat alone (*3*, *19*). In an effort to obtain reliable information on the composition of hog carcasses without the necessity of cutting, a "coring device" was constructed and tried in the Minnesota project (*4*). Reasonably high relationships were found between the lean content of "core samples" and the yield of primal cuts. The highest correlation found was +0.79 between the lean content of a "core sample" and the total lean content of the carcass, the "core sample" being taken from the belly between the 5–6 ribs. Yield of the primal cuts was correlated with the percentage of lean in the "core samples," +0.61 for the 5–6 and the 11–12 rib belly samples. Fat content of "core samples" showed lower relationships to total fat content of carcasses than was the case for lean tissue.

In the Oklahoma project specific gravity was tried as an indicator of fatness of hog carcasses (*11*). Split halves of carcasses were immersed separately in water and weights were obtained while the half-carcasses were suspended in the water. Percentage yield of the lean cuts was correlated more closely with specific gravity (+0.84) than with back fat thickness (−0.72). Similarly, the percentage of fat cuts was correlated more closely (−0.78) with specific gravity than with back fat thickness (+0.69). These results indicate that the fat or lean content of hog carcasses may be estimated as accurately by specific gravity technique as by using percentage of fat cuts or of lean cuts.

Practical means of estimating accurately the differences in fatness of live hogs which could be used in experimental selections are needed. A method has been developed which may be useful for that purpose (*43*). A lancet is used for puncturing the skin at selected points over the back and a narrow metal ruler with a blunt end is inserted and pressed through the layer of fat to the muscle. Readings taken on the ruler indicate the thickness of fat. Such measurements taken on live hogs before slaughter were slightly more accurate as indicators of leanness and yield of primal cuts than the measurements of back fat thickness on the carcasses after slaughter. Trial of this technique for selection purposes is in progress.

Over-all results in projects of the laboratory show that, through the crossing of selected inbred lines, it is possible to produce carcasses with approximately the characteristics desired; further, that this can be done without sacrificing growth rate or economy of gain. However, when one parent line is known to produce excessivly fat carcasses but has other good qualities which warrant its use, the other parent should be from a line known to yield definitely leaner carcasses than the former.

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